Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

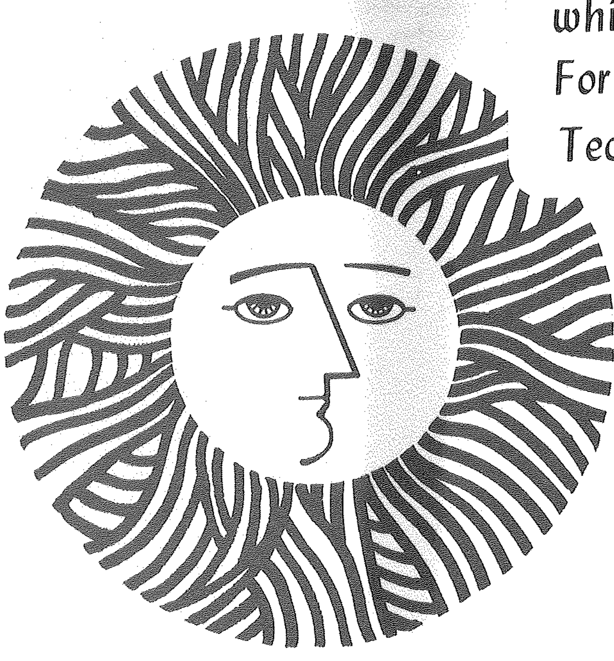
ENERGY & ENVIRONMENT DIVISION

VENTILATION/ODOR STUDY
FIELD STUDY
FINAL REPORT

Volume I

R.A. Duffee and P. Jann

April 1981



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VENTILATION/ODOR STUDY
FIELD STUDY

Final Report

Volume I

R.A. Duffee and P. Jann

TRC Environmental Consultants, Inc.
Wethersfield, Connecticut

April 1981

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Lawrence Berkeley Laboratories
Ventilation/Odor Study
Field Studies of Final Report
Phase II

Volume I

TRC Environmental Consultants, Inc.
December 1980

R. A. Duffee
Project Manager

P. R. Jann
Sr. Project Scientist

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1.0 EXECUTIVE SUMMARY

This report presents the results of field studies conducted to explore the potential for saving energy by reducing ventilation rates in public buildings. Modern ventilation standards are based largely on the results of chamber experiments conducted in the 1930's.[1] Admittedly incomplete in their time, these experiments indicated a need for ventilation rates commensurate with today's standards to control occupancy odor. They also indicated a need to increase ventilation rate per person with higher occupancy rates.

Two types of experiment programs have been initiated to determine the validity of these earlier findings based on today's personal hygiene standards and using modern analytical facilities and techniques of psychophysical evaluation. The work reported here consisted of measuring the actual fresh air ventilation in some public buildings, evaluating the indoor odors, and determining whether or not a reduction in ventilation rate results in a significant increase in odors. The relation between organic compounds, including odorants, and ventilation rate was also measured in-situ in selected buildings.

Results of two types of field studies conducted by TRC in schools, hospitals, and an office building in the period between January, 1979 and December, 1979 are presented. Dr. Andrew Dravnieks, a consultant to LBL, contributed to the design of the field studies and to the data analyses.

The primary experiments were conducted at four buildings in different parts of the United States: two elementary schools (Fairmoor School, Columbus, Ohio, and Oakland Gardens School, Queens, New York City); one hospital (the University of Connecticut Medical Center, Farmington, Connecticut); and one office building (San Francisco Social Services Building). Two consecutive weeks were spent at each of these buildings, usually in concert with the LBL indoor air quality staff and trailer. During one week, up to three selected areas in each building were maintained at their normal ventilation (fresh air supply) condition. During the other week, the ventilation was reduced by closing or covering the ventilation system intake.

A secondary experiment was conducted at 13 additional buildings, seven schools and six hospitals. The objectives of these measurements were: to indicate the potential energy savings through reduced ventilation in public buildings by measuring existing fresh air ventilation including infiltration; to develop data on the influence of climatic factors, if any, on ventilation rates and odor levels; and to identify the variety of odorants and odorant concentrations. The latter measurements were to serve as input to the chamber experiments being conducted at the John B. Pierce Foundation.

The primary conclusions determined by this study are:

- Sensory odor levels were found to be quite low in most buildings tested. Inside air was no worse than two to three times more odorous than outside air for detectability, and less than one scale unit for intensity.

- A three-to-five-fold reduction in the fresh air ventilation in schools, hospitals and office buildings can be achieved without significantly affecting perceived odor intensities or detectability. In many cases the ventilation rates were much higher than the code-specified rates. A simple reduction to the code values would result in significant energy savings.

- Tobacco smoking was found to be the most significant, pervasive contributor to interior odor level in the buildings tested.

- Total hydrocarbon content of indoor air varies directly with ventilation rates; odor, however, does not as most odorants remain below their detectable threshold concentration with reduced ventilation.

- The data collected thus far are too sparse to firmly establish the minimum ventilation rates required for odor control, but certain rates* can be suggested. We find that occupant density does not contribute to measurable differences in indoor odor levels, in the range of one person per 30 $feet^2$ to one person per 230 $feet^2$.

  In schools, without smoking, the minimum rate is 2.0 CFM/person or 0.4 ACPH.

  In hospitals, considerable reductions can be realized, down to the order of 5 CFM/person or 0.5 air change per hour in nonsurgical areas, patient rooms, nursing stations, and administrative/waiting areas (without smoking).

  In office areas, with restricted smoking, similar rates of 5 CFM/person are possible.

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* These rates assume that intensity levels of 3.0 or less on the butanol scale; and ED_{50} values of 12 or less, are acceptable to both visitors and occupants.

2.0 INTRODUCTION

This report presents the results of field investigations conducted by TRC Environmental Consultants, Inc. (TRC) in schools, hospitals, and an office building on the relation between ventilation rate (outside air supply) and odor within the buildings. The primary objective of this study was to determine: the reduction in ventilation rates that could be achieved in public buildings without causing adverse effects on odor; the sources of odor in public buildings; and the identity of the odorants. The studies reported here were conducted between January, 1979 and December, 1979.

These investigations are part of the Lawrence Berkeley Laboratory's (LBL) Energy Efficient Buildings Program, Energy and Environment Division, Craig Hollowell and Arthur Rosenfeld, principal investigators. The variables of particular interest included: type of odor (occupancy, tobacco, etc.), occupant density, odorant identity and concentration, differences in impressions between occupants adapted to prevailing conditions and visitors, and the influence of temperature and humidity on both the generation and perception of common contaminants. These variables were investigated in laboratory experiments conducted by the John B. Pierce Foundation in a new aluminum-lined environmental chamber, and in field studies conducted by TRC in schools, hospitals, and office buildings.

The field experiments reported here were aimed at determining the applicability of relations developed in the chamber experiments at the Pierce Foundation to field situations. Further, the field studies were designed to develop information on odorant identity and concentration to be used to guide the chamber experiments.

Four types of evaluations were made during the field program: sensory odor measurements, chemical measurements, fresh air ventilation measurements (including infiltration), and acceptability evaluations via questionnaires. Samples of room air and outside air were evaluated for detectability by the forced choice triangle olfactometer technique[2] and for intensity by comparison to a binary butanol scale[3] in TRC's Mobile Odor Laboratory. The dynamic forced choice triangle olfactometer minimizes the anticipatory and desensitization effects associated with some other measurement methods. The butanol scale for intensity provides a way to measure the intensities of odors having different characteristic smells by comparing them to a standard odorant, 1-butanol.

Chemical measurements were made in order to identify and quantify the odorants found in public buildings. Samples were collected by adsorption on Tenax and analyzed by Illinois Institute of Technology Research Institute's (IITRI's) odorogram technique and by gas chromatography/mass spectrometry. In this way, each individual peak detectable by gas chromatography was described as to its odor quality, if any, and was also identified chemically.

Ventilation rates were measured using a sulfur hexafluoride (SF_6) tracer technique. In this procedure, a small quantity of SF_6 is released in the room being tested and periodic syringe samples are taken. Samples are analyzed on a gas chromatograph equipped with an electron capture detector. The exponential decay curve is plotted on semi-logarithmic paper and from it the total and fresh air ventilation rates, and thus the recirculation rate, can be determined.

Measurements of the acceptability of the indoor air quality were made by administering questionnaires to both occupants and visitors (odor panelists) to obtain a comparative rating for the two groups. The questionnaires used were devised by Copley International and were modified versions of LBL's own form for evaluation of air quality acceptability as a function of ventilation rate.

This report (Volume I) details TRC's procedures and summarizes the results. Volume II contains the complete set of reduced data for the entire field program.

3.0 EXPERIMENTAL DESIGN

Two types of field studies were conducted by TRC. Primary experiments were conducted for an intensive two week period at each of four buildings under varied ventilation rates. Secondary one-day experiments were conducted at each of thirteen additional buildings with existing ventilation rates. Dr. Andrew Dravnieks, a consultant to LBL, contributed to the design of the field studies and to the data analyses.

3.1 Primary (Intensive) Studies

The primary experiments were conducted at four buildings in different parts of the United States; two elementary schools, one hospital, and one office building. A compatible schedule was developed in conjunction with the LBL indoor air quality staff and their EEB trailer laboratory in order to carry out the two studies coincidentally. The schedule followed and the buildings involved were:

1)	January 29, thru February 9, 1979	Fairmoor Elementary School Columbus, Ohio
2)	May 14, thru May 25, 1979	UConn Medical Center Hospital Farmington, Conn.
3)	September 17, thru September 28, 1979	San Francisco Social Services San Francisco, Cal.
4)	December 3, thru December 14, 1979	Oakland Garden School Queens, New York

The San Francisco office building was substituted midway through the project as an alternate to the originally scheduled second hospital. This was done partially to increase the scope of the study to include another type of building, and partially because of construction problems at the originally proposed hospital site.

Two consecutive weeks were spent at each of these buildings. During one week, up to three selected areas in each building were maintained at their normal ventilation (fresh air supply) condition. During the other week, the ventilation was reduced by closing and/or covering the ventilation system intake. The ventilation reductions were controlled by LBL staff, except for the UCONN Medical Center where TRC staff were responsible. Experiments in which the ventilation rate was changed on an irregular basis were run at the initial building (Fairmoor Elementary School) to determine whether weekends or day of week had any effect on measured odor levels. No significant differences were found, so in all other buildings the ventilation systems change over occurred only once.

The Fairmoor Elementary School, Figure 3-1, was constructed in 1960 and is located in an eastside residential area of Columbus, Ohio. A third grade (Room 12) and a fourth grade (Room 20) were chosen as test areas in addition to the multi-purpose gymnasium. Each classroom had a unit ventilator with individual outside fresh air intake and a closet exhaust in the coatroom which vented to the hallway. Classroom occupancy averaged 25 to 30 students. The gymnasium had two large overhead supply ducts alongside the stage with return air exhausted underneath the stage. Occupancy of the gym varied from 0-40 depending upon time of day and day of week.

The UCONN Medical Clinic and Hospital was constructed in 1974 and consists of an oval combination structure of a 3-story hospital/clinic and a 9-story school/research facility. Consequently, the ventilation systems were very complex with over 100 sub-systems. Supply air was drawn from the center courtyard at ground level and exhausted at roof level. For the hospital, this was at the same level as the 4th floor of the school. Figure 3-2 is an illustrated sketch of the layout of this facility. The areas chosen for testing were the 1st floor Admissions Module, a 2nd floor Post-Partum Nurses' station, and a patient room down the hall (Room 2116). The admissions and nurses' supply air was interconnected. Patient supply was on another system. Exhaust systems were also separate. Occupancy of the Admissions Module averaged 8-12, the nurses' station 6-8, and the patient room 0-2.

The San Francisco Social Services Building (SFSS) was constructed in 1978 and had been occupied one year at the time of this study. Only the first floor application interview area was investigated. It was a large triangular shaped room containing a waiting area (75 seats), a short-term child care nursery, and at least twenty interview and office cubicles for the SFSS workers. Ventilation to this area was suppled by a ceiling light/vent system (LUMINAIR) which was interconnected to the rest of the first floor. See Figure 3-3 for illustrated sketch and sampling locations. Averge occupancy including applicants and workers ranged from 80-100.

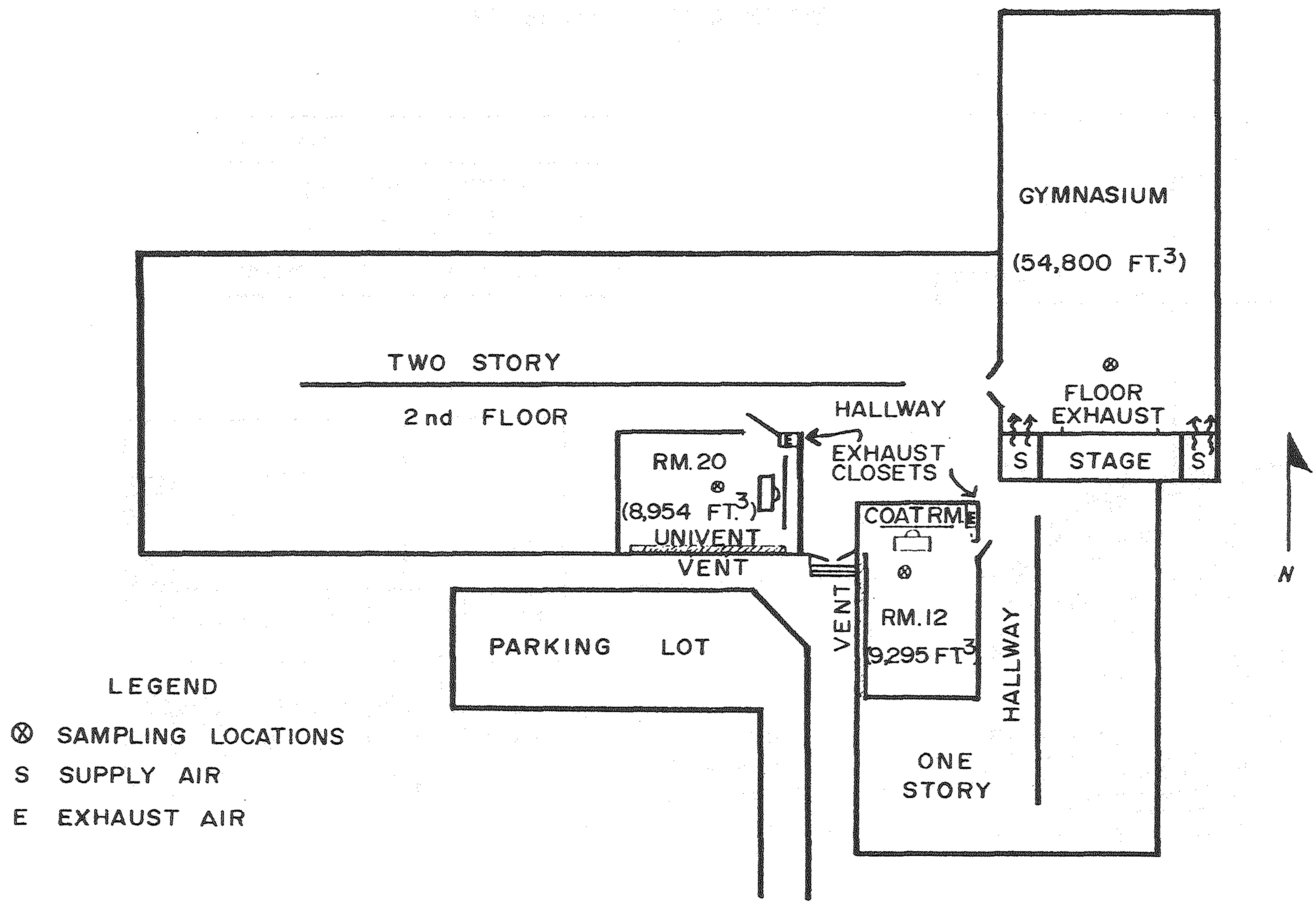


FIGURE 3-1: FAIRMOOR ELEMENTARY SCHOOL
COLUMBUS, OHIO

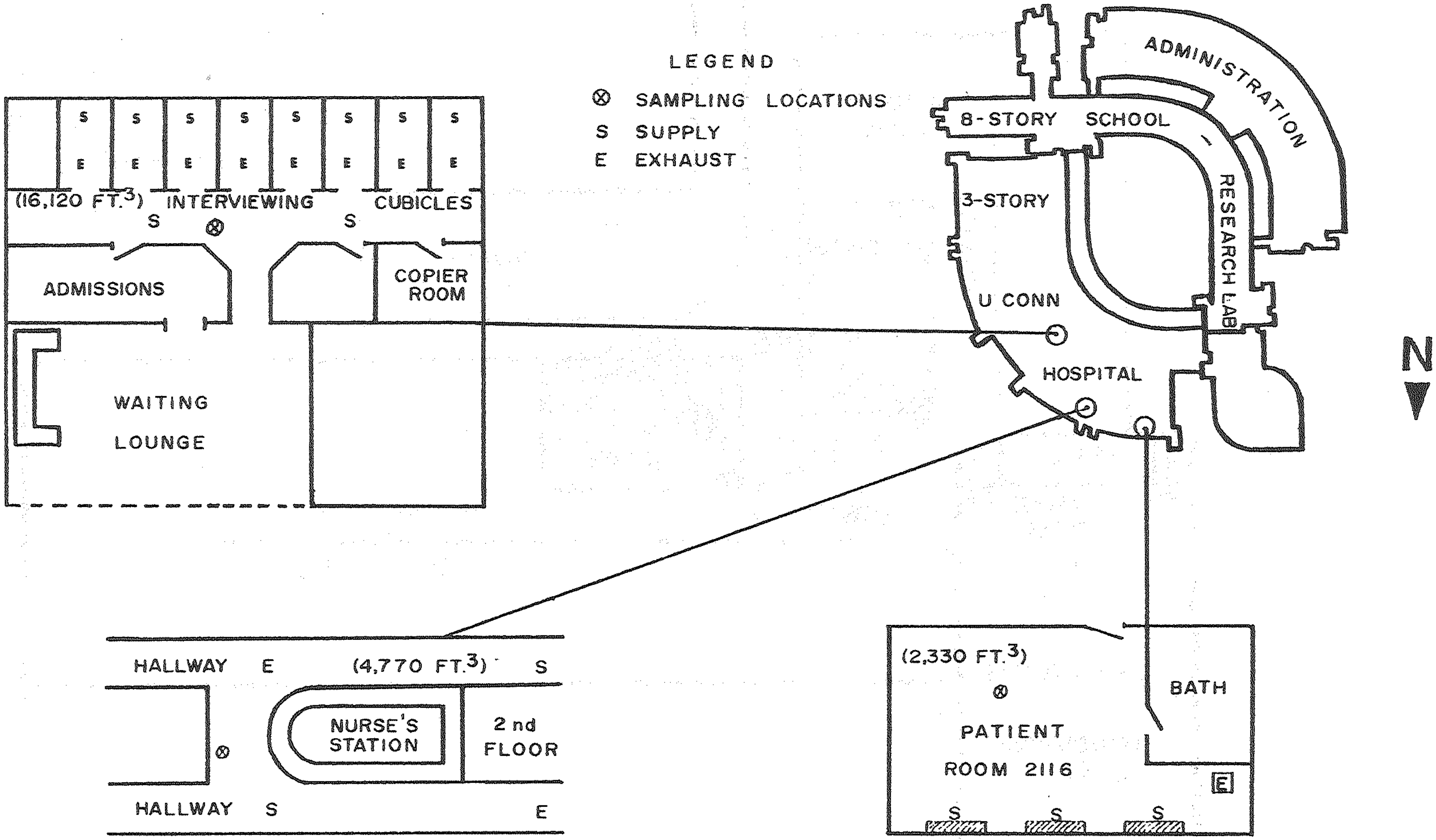


FIGURE 3-2: U CONN MEDICAL CLINIC
FARMINGTON, CONNECTICUT

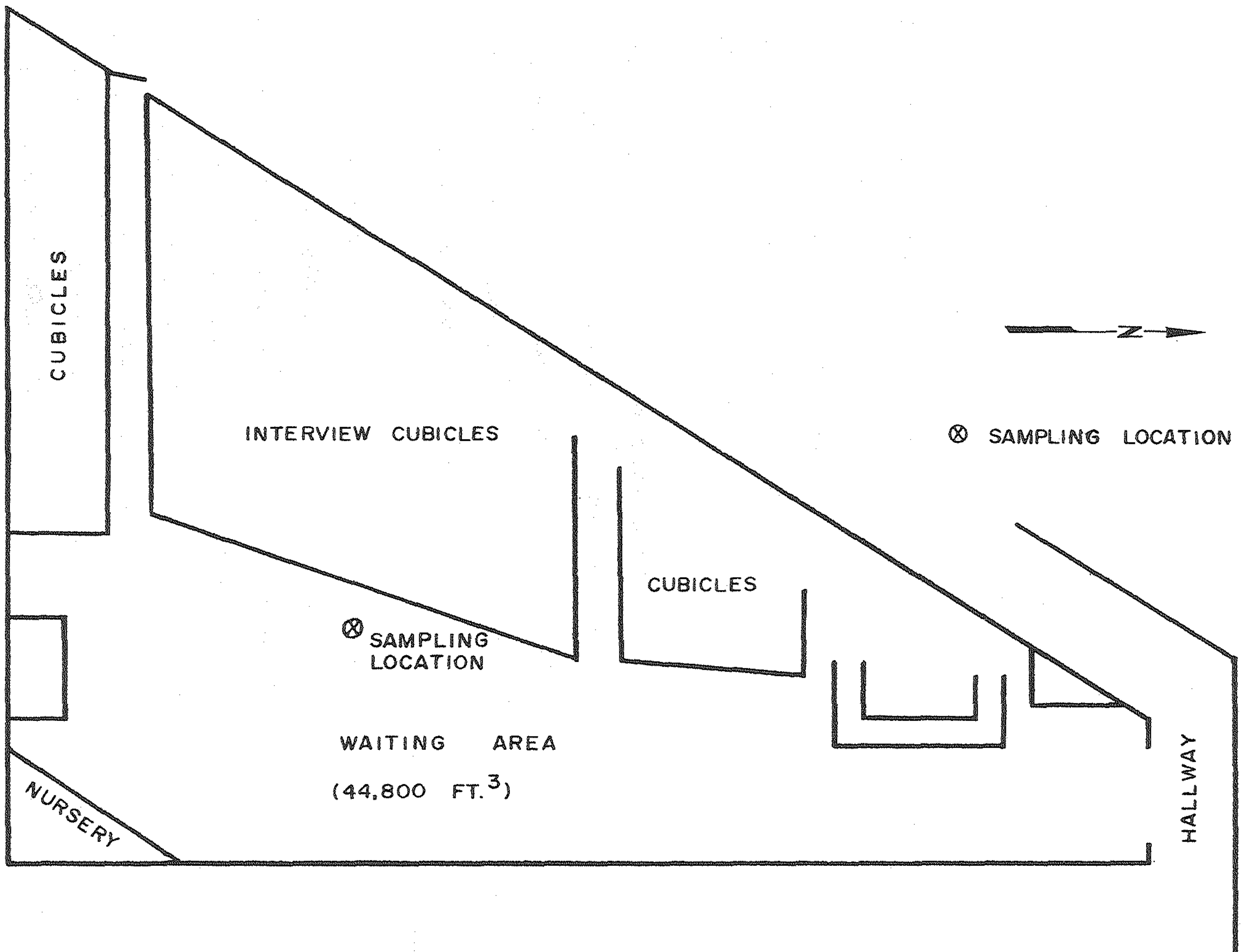


FIGURE 3-3: INTERVIEW AREA
SAN FRANCISCO OFFICE BLDG.
CALIFORNIA

The Oakland Garden School, located in a residential area of Queens, New York, was constructed in 1961. Two fifth grade classrooms located on the 3rd floor were chosen as test rooms, Rooms 323 and 325. Ventilation consisted of a single room exhauster with fresh air infiltration through window casements. A third classroom (Room 322 across the hall) was chosen as a control test for the questionnaire survey. Occupancy averaged 35-40 for each room. See Figure 3-4 for illustrative sketch.

3.2 Study of Existing Conditions

The secondary experiments were conducted at 13 additional buildings, seven schools and six hospitals, on both the east and west coasts. The objectives of these measurements were: to indicate the potential energy savings through reduced ventilation in public buildings by measuring existing fresh air ventilation including infiltration; to develop data on the influence of climatic factors, if any, on ventilation rates and odor levels; and to identify the variety of odorants and odorant concentrations. The latter measurements were to serve as input to the chamber experiments being conducted at the John B. Pierce Foundation.

In these experiments, no changes were made to the ventilation system; we measured fresh air ventilation as found. Also, no survey questionnaire of acceptability was conducted. For each building one set of sensory samples, along with a set of GC/odorogram samples, were collected for each of three areas in each building on one day. Ventilation was measured, in each of the three areas, by the SF_6 tracer technique.

Seven of the buildings selected were located in Connecticut, the other six in the Long Beach, California area. The seven schools and six hospitals were selected to provide a range in construction materials, insulation, ventilation and air conditioning systems. They included a 1930 brick school building with window ventilation; a WWII army barracks converted to a hospital with ventilation provided by wall air conditioners, and a modern (1974) tightly constructed hospital facility with a very complex ventilation system. The buildings on the east coast were studied primarily during the heating season. Those on the West Coast were sampled in September 1979 during a period of high temperatures (mid-90's) and smog. Some of these buildings were air-conditioned, while others, of similar structure and occupant density, were not.

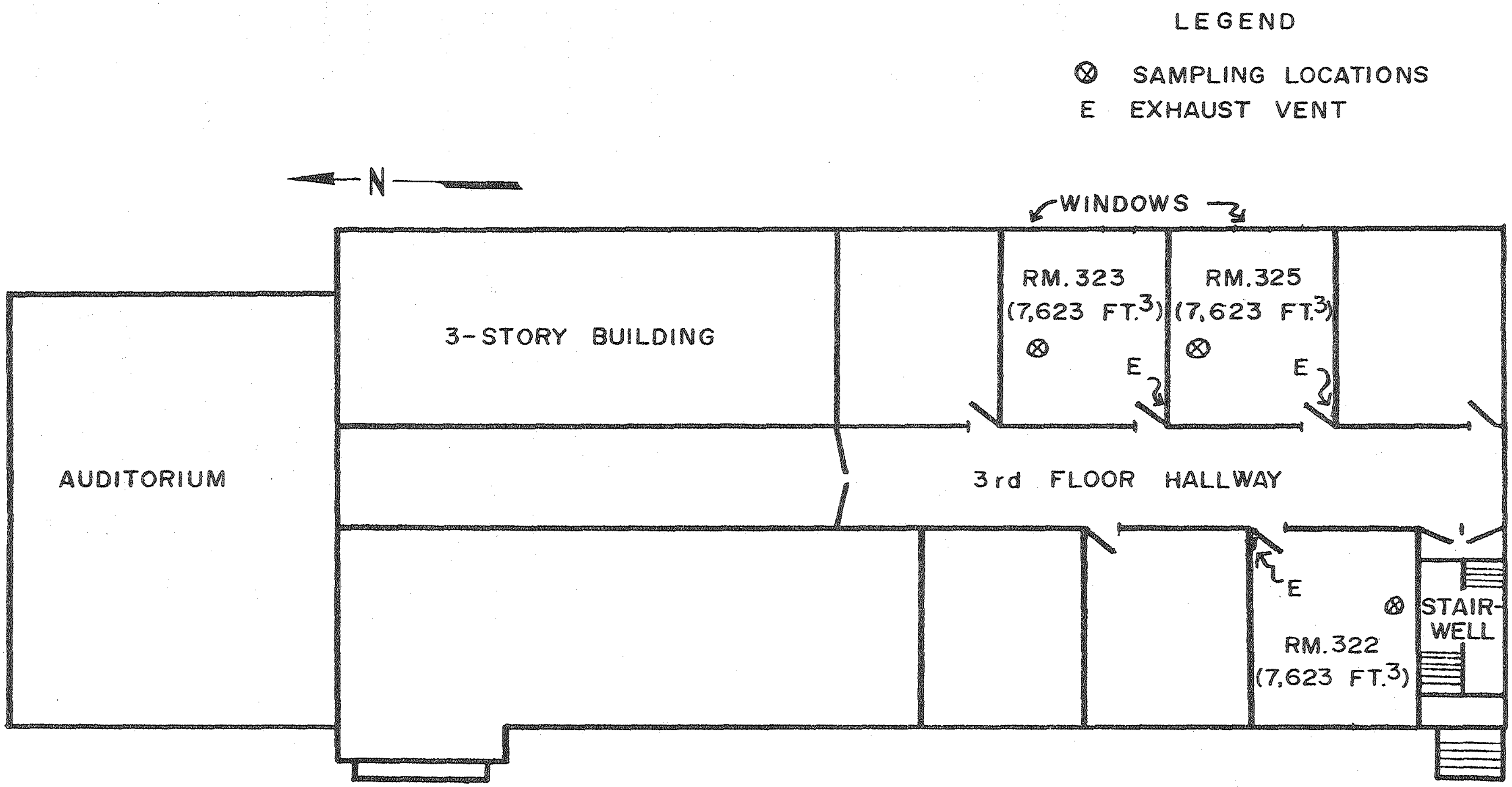


FIGURE 3-4: OAKLAND GARDEN ELEMENTARY SCHOOL
QUEENS, NEW YORK

4.0 METHODOLOGY

The facilities and the experimental procedures used in this study to characterize building interior environments for odors and odorants are described below. They included a mobile odor laboratory, two dynamic olfactometers for sensory measurements, tracer gas release technique for ventilation measurements; ambient chemical collectors for analysis of airborne organic compounds, and questionnaire surveys to establish the hedonic responses of occupants and odor panelists to the inside environment.

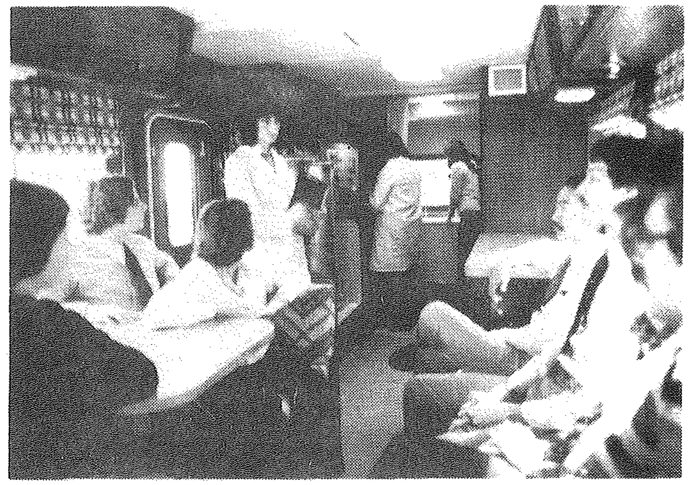
4.1 Mobile Odor Laboratory

The TRC Mobile Odor Laboratory, (MOL), as seen in Figure 4-1, was converted from a new 26-foot motorhome. It is fully self-contained with air conditioning, a 4.5 KW generator, an air deodorization and recirculation system, and seating capacity for up to ten odor panelists. An essentially odor-free environment is maintained in the mobile laboratory by keeping the van under slight positive pressure and recirculating 500 cfm of air continuously through activated carbon. The same air recirculation system is used to supply the dilution air to the sensory measurement devices.

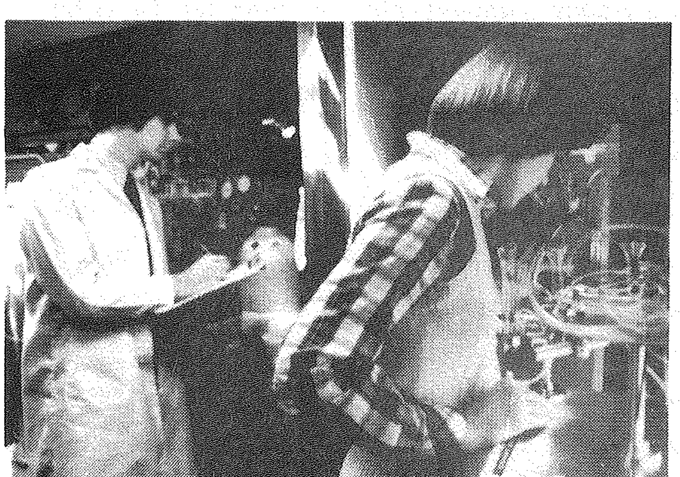
The mobile lab is equipped with two dynamic dilution olfactometers and several support systems. One of the olfactometers was developed at IIT Research Institute (IITRI) and was designed with the requirements of the ascending forced-choice technique (three alternatives per trial; threefold change in concentration from step to step). This device, when modified to deliver odorous air at 3 L/min as done for this work, ensures adequate flow for human inhalation and yields measures of detectability close to those obtained when subjects smell odorant in the ecologically valid situation (still air in a room). In the triangle technique a subject smells a sample of odorized air along with two blanks, and the panelist must pick out the odorous port from the two blanks of carbon purified air. For each triad, the sample of odorous air is three times more concentrated than the previous station. For ambient samples, five stations are used with dilution ratios of 81, 27, 9, 3 and undiluted. For stronger (source) odors six stations are used and the dilution ratios are 2150, 801, 248, 71, 30 and 10.

Based on the number of successive correct choices of each panelist, and a statistical consideration of one chance in three for guessing, the average detectability in terms of the median dilution ratio is determined for each

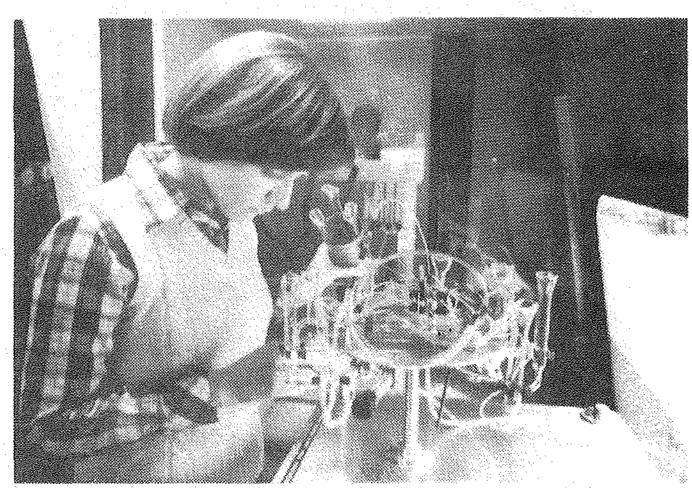
TRC MOBILE ODOR LABORATORY



ODOR PANEL RECEIVING INSTRUCTIONS



THRESHOLD ODOR MEASUREMENTS



COMPARATIVE ODOR INTENSITY

FIGURE 4-1: TRC MOBILE ODOR LABORATORY

sample. Panelist judgement patterns are converted to individual maximum likelihood odor thresholds and median detection threshold (ED_{50}) values are then calculated from the equation:

$$\log ED_{50} = \frac{\log \text{(Individual Thresholds)}}{\text{Number of panelists}}$$

The ED_{50} value represents the Effective Dosage at the 50 percent level; this is the dilution at which 50 percent of the panel would, and 50 percent would not detect the odor. The triangle procedure admits to minor variation in number of blanks, size of the concentration step, string of correct responses necessary to cease testing, etc., but incorporates two essential features: 1) it removes certain response biases inherent in techniques that may require responses of merely yes or no, and 2) it minimizes the problem of adaption inherent in the presentation of weak stimuli after strong.

The MOL is also equipped with a second dynamic dilution olfactometer for intensity measurements, i.e., the strength of the perceived odor sensation. The binary Butanol Intensity Scale presents eight concentrations of a standard reference odorant, n-butanol, through a series of capillaries and an odorant vapor generator. A butanol reference scale provides an olfactory analogue of the phon scale (decibel). The butanol olfactometer (lazy susan configuration, as shown in Figure 4-1) delivers butanol vapor concentrations ranging in odor intensity from weak to strong and a subject seeks to choose the one port out of eight that matches any given test stimulus. If the test stimulus seems of an intensity that falls between adjacent ports, then the subject may so indicate. The range of concentration of butanol vapor is 16 to 2000 ppm from one port to another. Each successive port has twice the butanol vapor concentration of the previous port at a flowrate of 160 ml/min. However, the butanol scale numbers (1-8) do not numerically reproduce the relative perceived odor intensities, i.e., Port #3 does not smell 50% stronger than #2. The butanol vapor concentration in #3 is two times higher than in #2. From the psychophysical relationship for butanol, relating concentration to perceived intensity (ASTM E544, Appendix X3), the odor of Port #3 is then $2^{0.66} = 1.58$ times stronger than Port #2, or 58% stronger.

The sample handling and flow control system for the MOL is depicted in Figure 4-2. Both olfactometers use carbon purified air which is supplied by two metal bellows pumps (1 & 2). Odorous air samples can be admitted directly

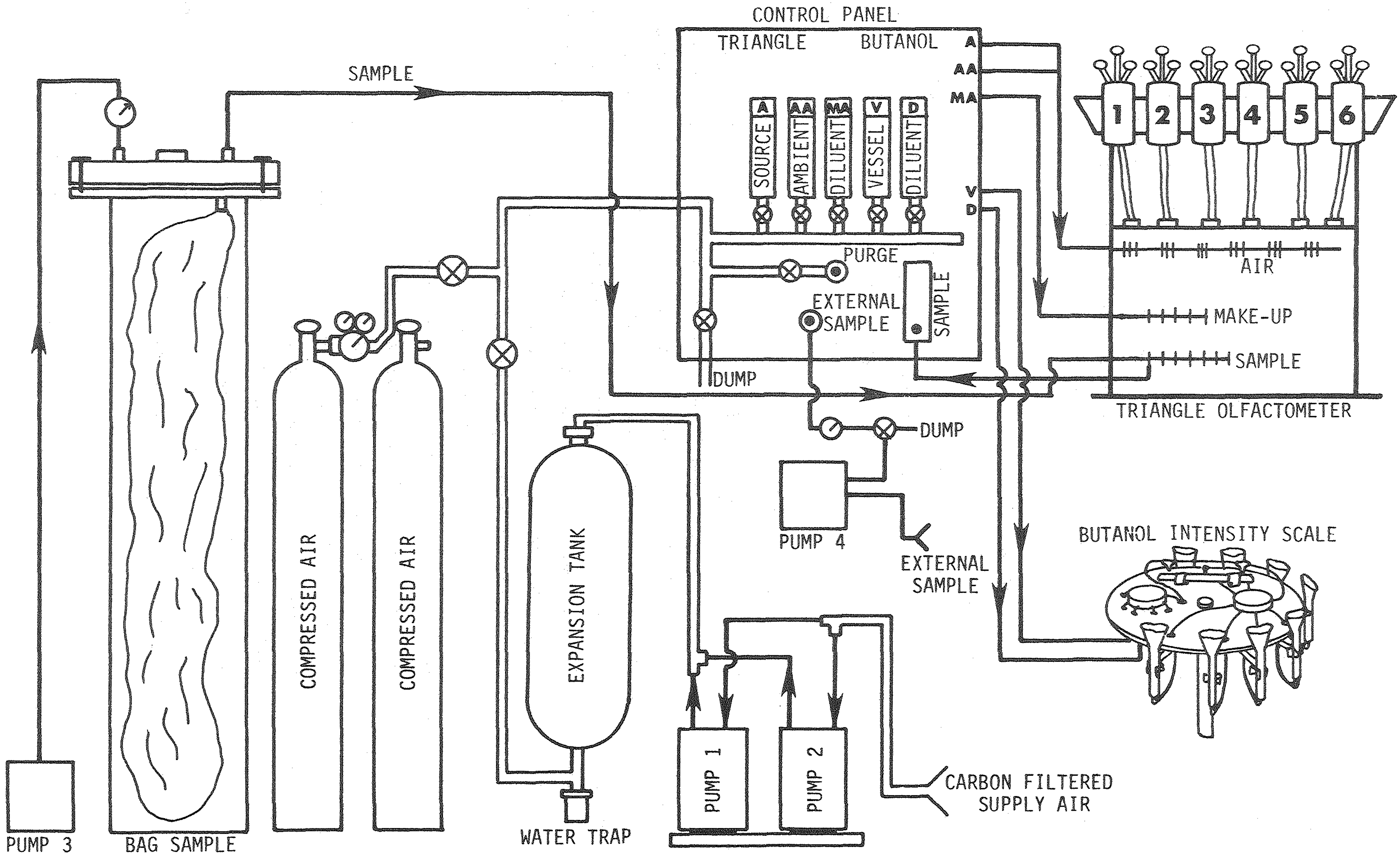


FIGURE 4-2 ODOR SAMPLING FLOW SCHEMATIC - MOBILE ODOR LAB

into the forced-choice olfactometer by means of a teflon lined diaphragm pump (pump 4) or discretely from a Tedlar bag pressurized externally (pump 3) in one of the two aluminum sampling drums. For the work reported herein, all samples were collected in Tedlar bags.

Other support systems include a portable gas chromatograph with electron capture detector for SF_6 tracer gas analysis and a collapsable ten foot meteorological tower installed on the MOL's roof with sensors to record wind speed, wind direction, and ambient temperature.

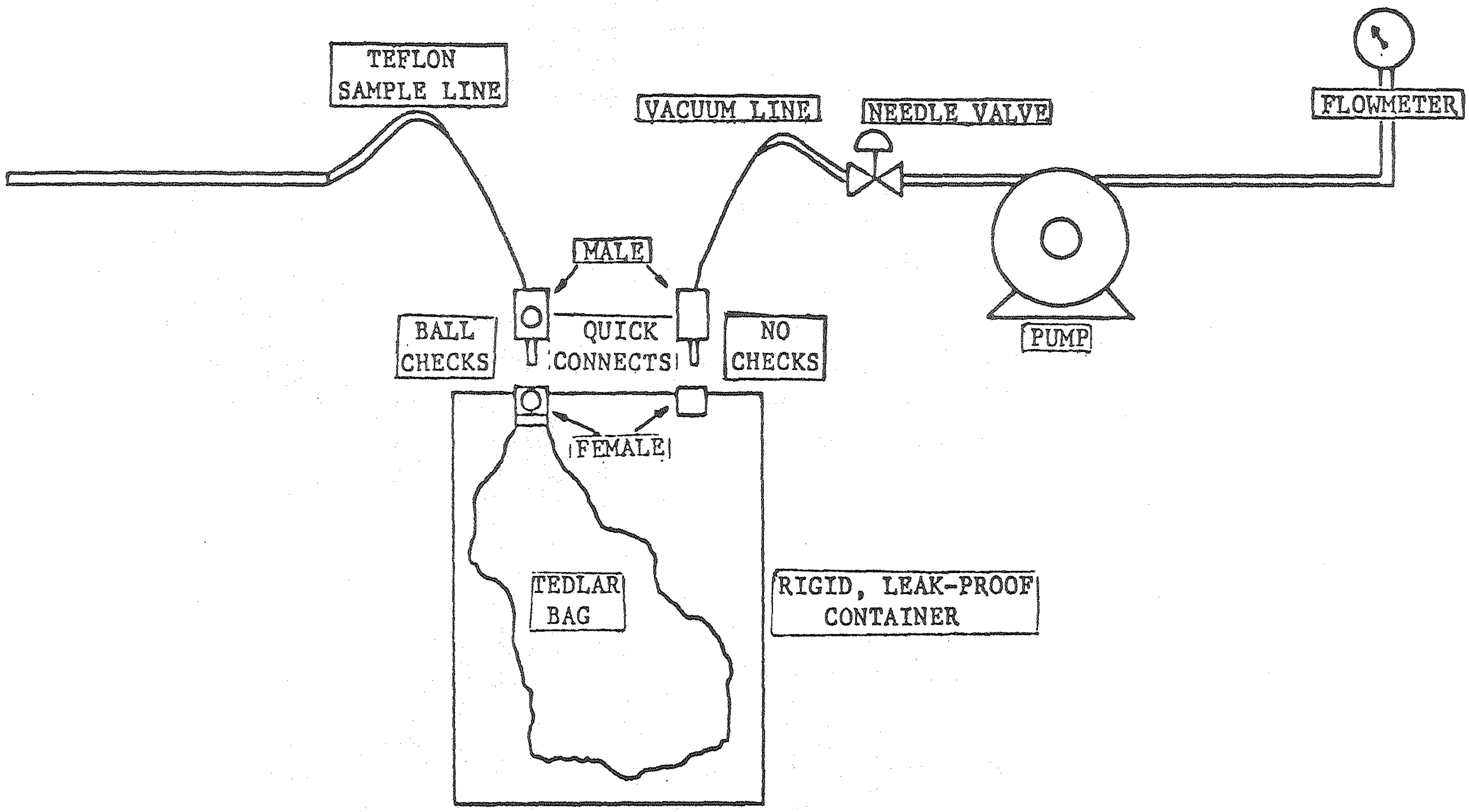
4.2 Sensory Odor Measurements

A ten member odor panel was recruited locally at each site from nearby colleges or market research firms. The exception was at UCONN Medical Center where TRC's professional odor panel, comprised of individuals who have been evaluating odor detectability for eight years on TRC's dynamic olfactometer, was used. All sensory odor measurements were made in TRC's Mobile Odor Laboratory.

Each test area was sampled twice a day during the variable ventilation studies at approximately 10:30 - 11:30 in the morning and 1:30 - 2:30 in the afternoon. For the one day evaluations, samples were taken only in the morning. All samples for sensory analysis were collected in 80-liter Tedlar bags installed in an aluminum cylinder of 109 liter volume using the "bag-in-a-drum" technique illustrated in Figure 4-3. A bag preconditioning procedure of two partial fill/expulsions was used to minimize adsorptive wall effects. Sampling locations were centrally located in each room or area and at a height of 4-5 feet from floor level using minimal lengths of teflon tubing. Each sample was collected over a 20 minute period including preconditioning. Sensory samples, therefore, represent 5 to 10 minute integrated average values.

The bag samples were brought for analysis to TRC's Mobile Odor Laboratory, parked immediately outside the building under study. The evaluation of the sensory samples was accomplished within a maximum of four hours from sample collection. Each sample was presented individually to the ten members of the odor panel at various known dilutions using the Forced-Choice Triangle Olfactometer. The individual panelist's threshold dilution ratio was then ascertained, and a panel detection threshold at the fifty percent level (ED_{50}) was calculated. Figure 4-4 illustrates a typical panel response and the ED_{50} computation.

FIGURE 4-3



INTEGRATED BAG SAMPLING TRAIN

ED50 Evaluation Form for Ambient Odor Dynamic Triangle Olfactometer

UConn Medical Center Sample # 166

Admissions Area - AM 9:30 Reduced Vent.

Evaluation Date: 5/23/79 RESULT: Log ED_{50} = 0.908 ED_{50} = 8.1

Cons. No.	Panelist	Dilution Level Number 1	2	3	4	5	"6"	*Log Threshold	BUTANOL SCALE 1 →8 70°F	
		Correct Choice Would Be: (t = Top, c = center, b = bottom)						→From connections in olfactometer		
		Panelist Indicated: (x = correct; 0 = miss)								
1.	Ann	O_T	X	O_T	O_B	X		0.24	4	
2	Helen	O_B	X	O_B	X	X		0.72	5	
3	Ruth	X	X	O_B	X	X		0.72	2	
4	Donna Lynn	X	O_B	X	X	X		1.19	3	
5	Olga	O_T	O_T	X	X	X		1.19	5	
6	Marie	O_T	O_T	O_B	X	X		0.72	5.5	
7	Florence	O_B	O_B	X	X	X		1.19	4	
8	Lois	X	X	X	X	X		2.15	3	
9	Rosalie	X	O_T	O_B	O_B	X		0.24	4	
10	Martha	X	X	O_B	X	X		0.72	3	
		Sum (Log Threshold) =						9.08	38.5	3.9
		Sum (Log Threshold) / Number of Panelists =						0.908	= Log ED_{50}	

* Table for Conversion of Individual Judgment Patterns to the Individual Maximum Likelihood Odor Thresholds

Dilution Factors 81x	27x	9x	3x	1x	"1/3"	Log of Individual Maximum Likelihood Threshold	
Olfactometer Levels 1	2	3	4	5	"6"		
				0	(+)	-0.24	miss at No. 5 level *
			0	+		+0.24	No. 5 correct; miss No. 4
		0	+	+		+0.72	Nos. 4,5 correct; miss No. 3
	0	+	+	+		+1.19	Nos. 3,4,5 correct; miss No. 2
0	+	+	+	+		+1.67	only miss at No. 1 level
+	+	+	+	+		+2.15	all levels correct

*assumed that would detect correctly at 3x concentration from ambient

Panel Leader PJ

FIGURE 4-4: TYPICAL PANELIST RESPONSE FORM

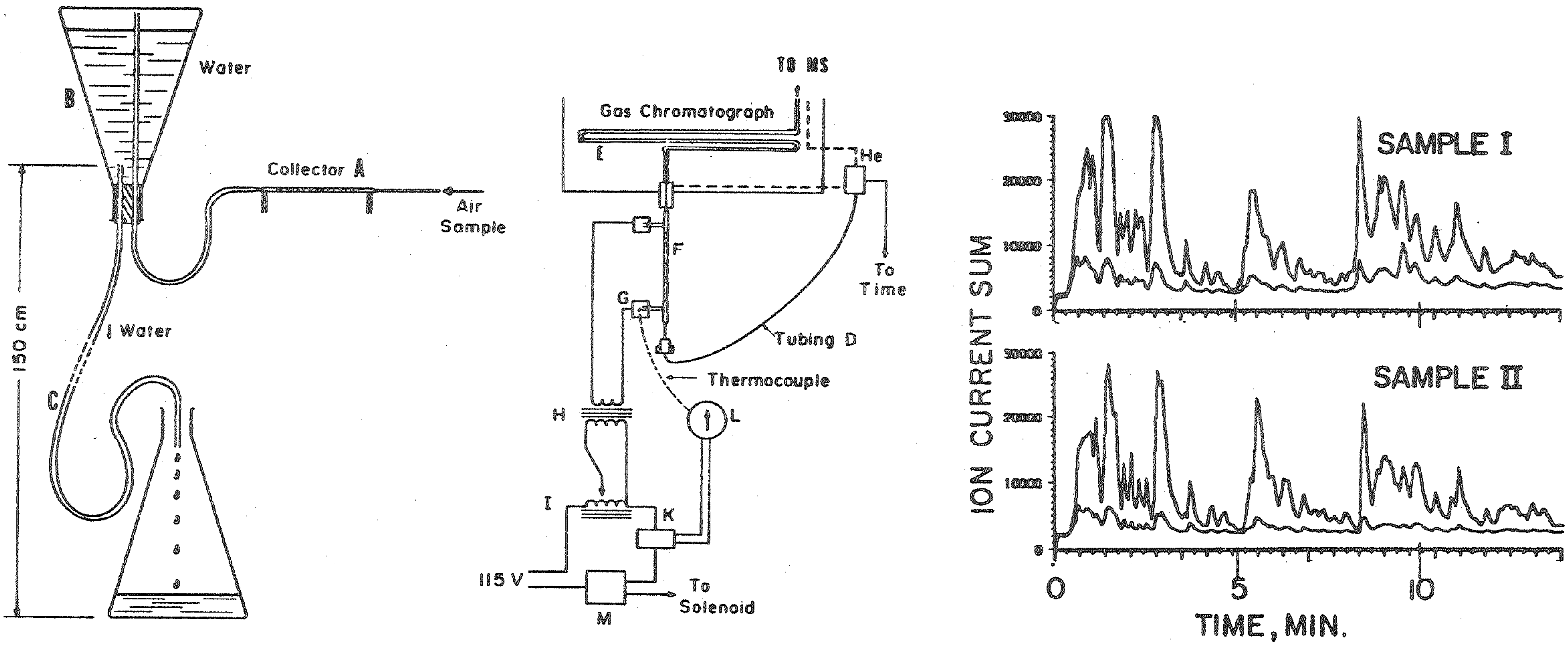
Each odor panelist matched his or her selected undiluted odor of each sample, i.e. the odor of port 6 on the triangle olfactometer, to the Butanol Intensity Olfactometer. The panelist indicated the choice of butanol olfactometer port by pointing to a number chart by the experimenter. Only one panelist at a time used the olfactometers. The other panelists were at the other end of the MOL (as shown in Figure 4-1) and could not see the responses of the panelist at the olfactometer.

Outside air was sampled routinely by the same bag-in-a-drum technique in order to determine the difference between inside and outside levels, i.e. the contribution of occupancy, smoking, cleaning compounds, building materials, etc., to perceived odor in the building. Carbon purified van air was collected in bags and evaluated by panelists to determine system "background" odor. This averaged 2 ± 1 ED_{50} units and 1.0 on the butanol intensity scale. New Tedlar bags had to be preconditioned 4-5 times with purified air before "plastic-background" levels reached these acceptable levels.

4.3 Chemical Measurements

Samples of air to be analyzed for odorous organic material were taken concurrently with sensory samples in each test area twice per day per condition by means of a portable, adsorbent collector technique developed by IIT Research Institute of Chicago. The collector, as shown in Figure 4-5a, is a 1/8 inch tubular probe packed with a very thermally stable polymeric adsorbent material called Tenax. It was attached to the suction side of a two liter flask filled with water. As the flask was emptied, a 2 liter sample was collected at a very slow, efficient rate, 30 to 50 ml/min. Collection efficiency was 90-95% @ 50 ml/min. flow rate. Sampling time varied from 30-60 minutes with no self-contaminating electrical pumps being required.

The samples were returned to the IITRI Laboratory and analyzed by either GC/odorogram or GC/MS techniques. The GC/odorogram method utilizes a flash desorbing step (Figure 4-5b) and a gas chromatograph with a 2:1 flow splitter after the analytical column. This enables some of the sample to enter the FID detector and the balance to go to a sniffing port. Each peak eluting from the column is smelled by a trained odor observer, and odorous peaks are noted on the chromatogram trace. If a GC peak is not accompanied by an odor in the sniffing port, the compound is either non-odorous or its concentration in the sample is below its odor threshold. Total hydrocarbon content of each sample



4-5a Collections

4-5b Flashing Desorbing

4-5c GC/MS Trace

FIGURE 4-5: CHEMICAL ODOR SAMPLING SCHEME was determined with FID response to dodecane ($C_{12}H_{26}$). In this way a measure of the organic material loading of interior air could be obtained for comparison to the sensory data and ventilation.

Both the GC/odorogram and the GC/MS techniques were employed for the four intensively studied (primary) buildings. The GC/MS analyses were used to chemically identify the compounds and odorants found on the GC/odorogram with sensitivity down to concentrations of 1 PPB. It utilized a capillary column GC with an ion source mass spectrometer (EID). The raw data was processed by a data-enhancement algorithm program and then went to a computer-based search system (Biemenn method) Figure 4-5c.

4.4 Ventilation Measurements

The fresh air ventilation rate of each room or area in the test buildings was measured at least once per day during the variable ventilation studies using a non-toxic atmospheric tracer gas, sulfur hexafluoride (SF_6). Professor Frederick H. Shair of the California Institute of Technology guided the ventilation studies. A small quantity of SF_6, typically 5 to 10 cm^3, was released and mixed with room air. Grab samples of room air were taken at one minute intervals for 10 minutes and 5 minute intervals thereafter for a period of an hour using 35 cm^3 disposable plastic syringes with air-tight caps. Portable mixing fans were used during the first 4 minutes of tracer release in order to insure rapid mixing. The samples were then analyzed by an AID portable electron capture gas chromatograph and decay plots of concentration vs. time were prepared. The fresh air dilution can be calculated from the equation:

$$q = \frac{V}{t_2-t_1} \ln (C_1/C_2)$$

Where q = ventilation rate (CFM)
v = volume of room (ft^3)
t = time of sample (min)
C_t = tracer concentration at time t in ppb

A typical plot is shown in Figure 4-6 for a non-circulating system. For a recirculating system a two slope decay curve, as illustrated in Figure 4-7, is obtained. The early slope represents the total supply air flow, q_1, which dilutes the room air tracer concentration. The second more gradual slope shows the fresh air/infiltration portion, q_2, of the total air flow. If no

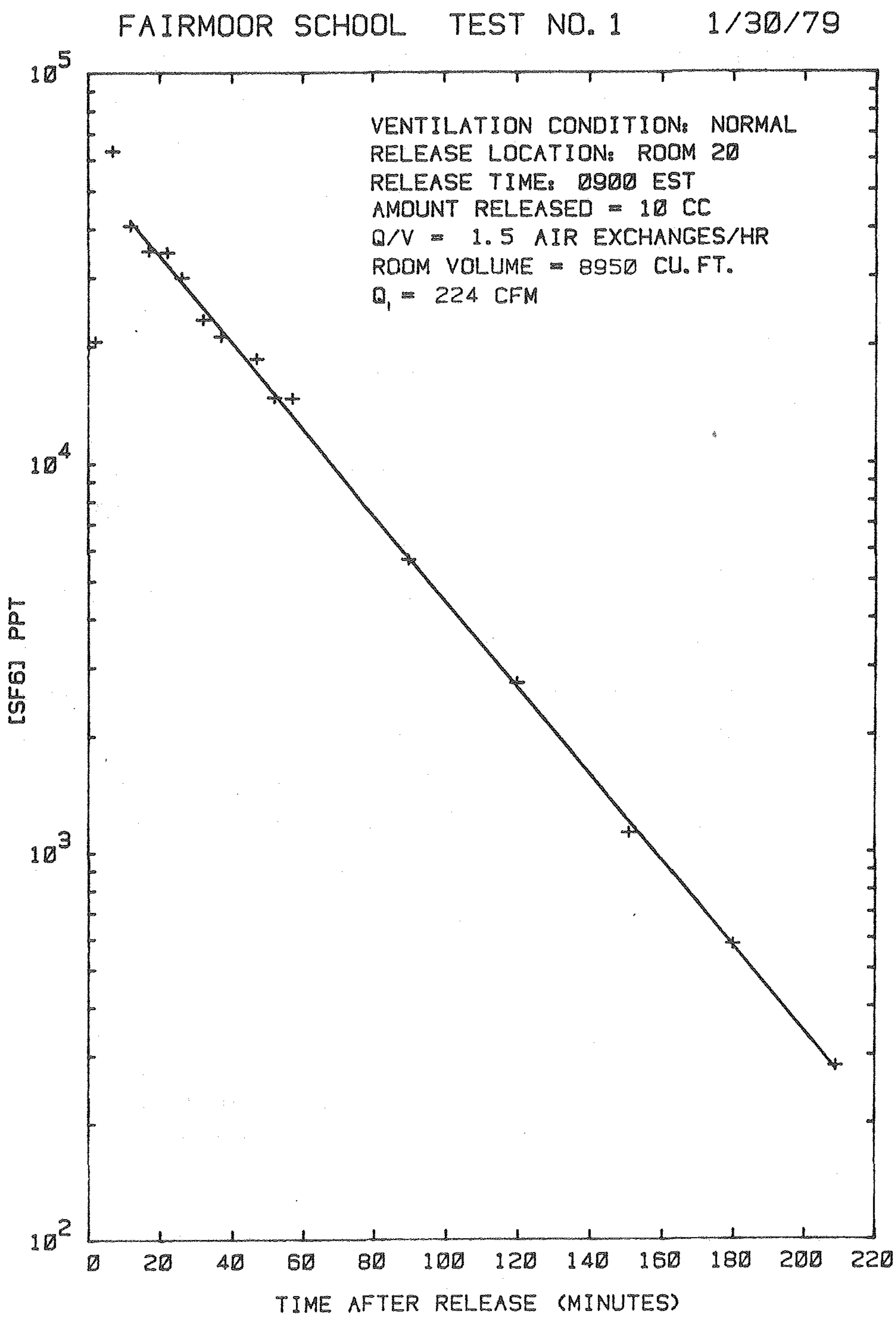


FIGURE 4-6: FAIRMOOR SCHOOL - VENTILATION MEASUREMENT

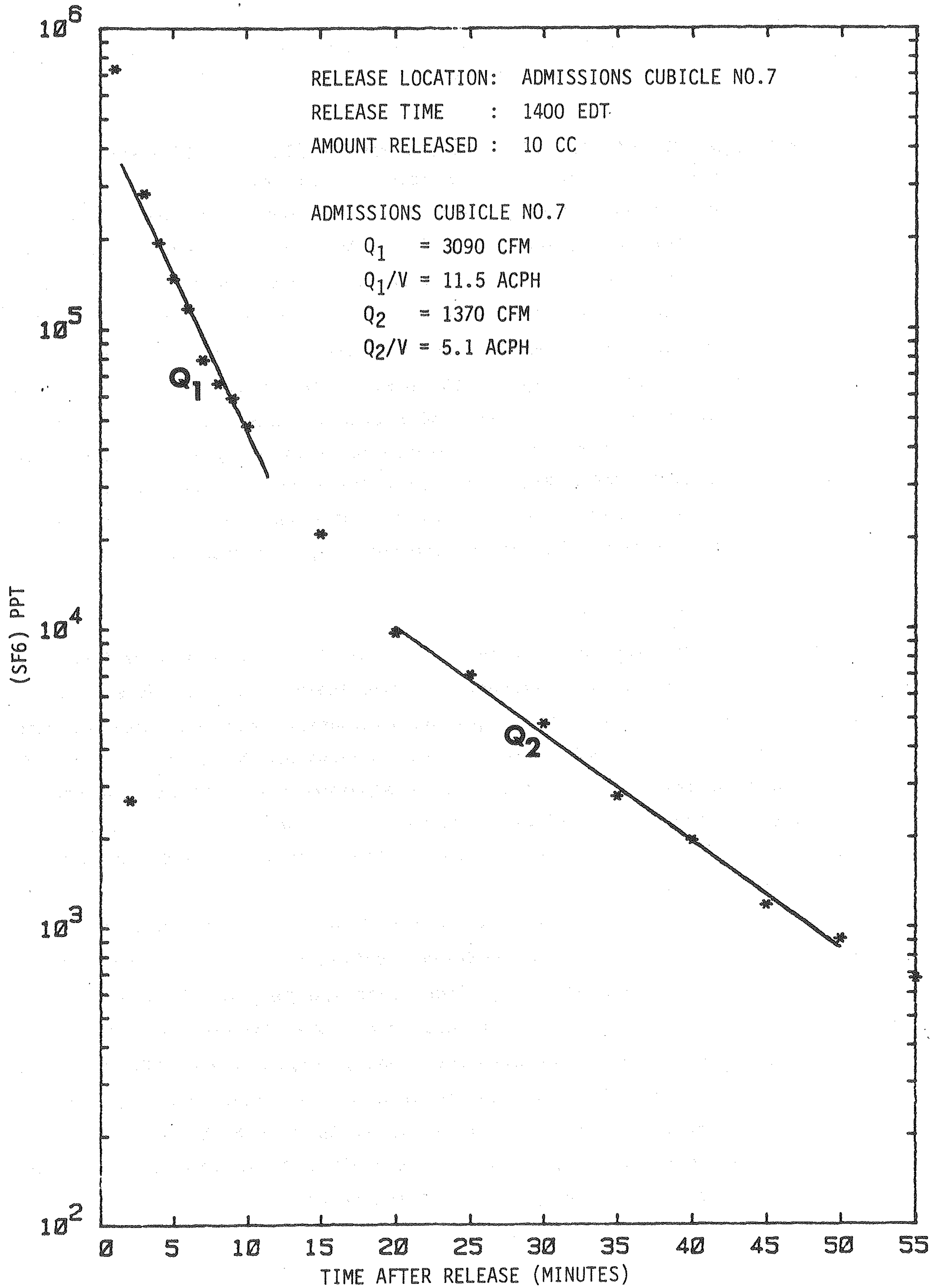


FIGURE 4-7: UCONN HEALTH CENTER TEST NO.36 5/25/79

fresh air supply or infiltration occurred the tracer concentration would remain constant once mixed within the total system.

4.5 Questionnaire Survey for Perceptual Evaluations of Indoor Environment

A set of forms and instructions developed in the previous phase were prepared for use by school, hospital, and office workers and by members of the TRC odor panels. The purpose of this work was to provide a means of measuring the evaluative responses of such personnel to changes in room ventilation, using the respondent's own category estimate on a scale of 1 to 9. Odor panelists and occupants completed the questionnaire once per day. Upon arriving at the test building (usually at 1:00 p.m. to 2:00 p.m.), the 10 panelists first visited each of the three areas under study. Immediately upon entering the room, they filled out the survey questionnaire of acceptability developed and administered by R. David Flesh of Copley International Corporation (CIC). Between visits to each room, they returned to the outside of the building for a few minutes to "de-adapt" themselves from building condiditons.

o PLAN OF APPROACH

The initial step was to consider a variety of forms and questionnaires used successfully for similar purposes. It was learned that Lawrence Berkeley Laboratory (LBL) had already developed an evaluation form and used it with reported success at Carondolet High School in Concord, California. The form was designed specifically to measure the evaluative responses of students in classrooms to changes in ventilation rates and was obviously appropriate for consideration in this study. The LBL form is shown in Figure 4-8; it consists of two pages.

Since the LBL form has been used and the data base is available for comparison, it was decided to use a modified version of that form. The changes were held to a minimum so that comparisons with the existing data base could be made by the Laboratory at some future time. The modification considered most important was to add a mechanism for school, hospital, and office workers to indicate whether they felt the individual elements evaluated are at acceptable or unacceptable levels. This information is essential if one of the major objectives of the study is to be met--viz., to develop standards of acceptable odor levels for the type of building tested.

LBL Form

Subjective Evaluation of Indoor Environment

The Lawrence Berkeley Laboratory, under contract to the U.S. Department of Energy, is conducting research and development work in the area of energy conservation in buildings. We are asking you to assist us in this project by filling out a questionnaire which solicits your subjective response to various questions related to the indoor environment at Carondolet High School.

Instruction to Subjects

Look over the list of adjectives that can be used to describe how the environment in this room feels to you. Take a few minutes to get into the mood of the situation and then complete the ratings according to the following instructions. Please do not discuss your own responses with other students in the room.

If you feel that the environment can be described very closely by the adjective at one end of the scale, you should place your checkmark as follows:

Hot __✓__ : _____ : _____ : _____ : _____ : _____ : _____ : _____ : _____ Cold

or

Hot _____ : _____ : _____ : _____ : _____ : _____ : _____ : _____ : __✓__ Cold

If you feel that the environment can be described as neutral, then you should place the checkmark as follows (except for question (1) where the central position indicates a moderate odor is present):

Hot _____ : _____ : _____ : _____ : __✓__ : _____ : _____ : _____ : _____ Cold

Intermediate descriptions of the environment should fall between the neutral position and the appropriate extreme position.

PLEASE: 1) Place your checkmark in the middle of the spaces.

2) Do not omit any.

3) Do not put more than one checkmark to a question.

FIGURE 4-8a: SUBJECTIVE EVALUATION OF INDOOR ENVIRONMENT FORM

LBL Form

Date_______________________________Room No.________________

Male_________Female_________

No odor	1	2	3	4	5	6	7	8	9	Strong odor
Pleasant odor	1	2	3	4	5	6	7	8	9	Unpleasant odor
Cold	1	2	3	4	5	6	7	8	9	Hot
Drafty	1	2	3	4	5	6	7	8	9	Stuffy
Humid	1	2	3	4	5	6	7	8	9	Dry
Quiet	1	2	3	4	5	6	7	8	9	Noisy

FIGURE 4-8b: SUBJECTIVE EVALUATION OF INDOOR ENVIRONMENT FORM

A Background Questionnaire was also added to the study. The Background Questionnaire was aimed at determining (1) whether differences in evaluations can be attributed to differences in the characteristics of the respondents, (2) the relative amount of time respondents spent in their rooms or areas of the building, and (3) which of the respondents had impaired sense of smell. Figure 4-9 shows the forms and instructions given to the adults who participated in the study. Figure 4-10 shows the evaluation form completed by the children at Fairmoor Elementary School in Columbus, Ohio, and at Oakland Garden Elementary School in Bayside, New York.

o LETTER OF INTRODUCTION

The letter of introduction, Figure 4-9a, entitled, "Study of Energy Conservation and the Indoor Environment" was given to all of the adult participants. It follows the same format used by Lawrence Berkely Laboratory in their letter of instructions (Figure 4-8), except that the explanation of the evaluation sheet was replaced by an Evaluation Schedule. Early disclosure of the ten-day Evaluation Schedule was meant to give the respondents a clear understanding of how often they were to be involved.

o EVALUATION SHEET AND INSTRUCTIONS

The Evaluation Sheet Instructions, Figure 4-9b, were a reduced version of that used by LBL. The example of "Hot" vs. "Cold" was replaced by "Light" vs. "Dark" to prevent the possibility of suggesting where the respondents would mark the "Hot" vs. "Cold" scale on the Evaluation Sheet. Since room temperature might be effected by changes in ventilation, it was felt essential to retain the "Hot" vs. "Cold" scale on the Evaluation Sheet.

The Evaluation Sheet, Figure 4-9c (continued), was designed to retain as many of the LBL scales as possible, although several changes to the LBL scales were made. For example, "Pleasant odor" vs. "Unpleasant odor" was replaced by the boxes labeled "Acceptable" and "Unacceptable." This was done to obtain results which could be used directly to help meet the study objective of developing standards of acceptable odor levels for the types of buildings under investigation. "No odor" vs. "Strong odor" was repositioned to second from the bottom. This was done for the three reasons. First, positioning a key question away from the beginning avoids bias associated with making the first response. Second, "Hot" vs. "Cold" seems easier for respondents to

STUDY OF ENERGY CONSERVATION AND THE INDOOR ENVIRONMENT

Subjective Evaluation of Indoor Environment

The Lawrence Berkeley Laboratory, under contract to the U. S. Department of Energy, is conducting research and development work in the area of energy conservation in buildings. We are asking you to assist us in this project by filling out Evaluation Sheets on which you can record your feeling about the environment of the room in this building in which you spend most of your time.

Specifically, we are asking you to complete an Evaluation Sheet at the time designated on as many of the ten days listed below as possible.

Evaluation Schedule

Refer to this schedule when you fill in the "Day Number" and "Date" at the top of the Evaluation Sheet.

Please begin your evaluation of the environment of this room at the time designated below. An Evaluation Sheet can be completed in just a few minutes. Once you begin, do not allow yourself to be interrupted or distracted. If it is necessary for you to be away from this room at the time designated, complete the form as soon as you return. Always fill in the actual time you begin your evaluation at the top of the form.

Day Number	Date	Time to Begin Evaluation
1	Monday, September 17	
2	Tuesday, September 18	
3	Wednesday, September 19	
4	Thursday, Septbember 20	
5	Friday, September 21	
6	Monday, September 24	
7	Tuesday, September 25	
8	Wednesday, September 26	
9	Thursday, September 27	
10	Friday, September 28	

Our survey supervisor will distribute new forms to you and make arrangements to pick up the forms you have completed on each of the days listed.

FIGURE 4-9a: VISITORS EVALUATION SHEET AND INSTRUCTIONS

EVALUATION SHEET INSTRUCTIONS

Rating of Individual Elements of the Room Environment

Six scales are provided for you to rate certain elements of the environment of this room. Take a few minutes to look over the Evaluation Sheet and to get into the mood of the situation, then complete the ratings according to the following instructions. Please do not discuss your own responses with others.

Each scale represents one element of the room environment. Concentrate on one scale at a time.

If you feel that the element can be described very closely by the adjective at one end of the scale, then place your checkmark as follows:

Light _√_:____:____:____:____:____:____:____:____ Dark

or

Light ____:____:____:____:____:____:____:____:_√_ Dark

If you feel that the element can be described by one of the spaces between these extremes, then place your checkmark on the space which you feel is most appropriate.

Each time you complete a rating, note whether you consider that element of the room environment to be "Acceptable" or "Unacceptable." Do this by placing a checkmark in the appropriate box to the right of the scale.

Please:
1. Place your checkmark directly on the space of your choice.
2. Rate all of the scales, do not omit any.
3. Do not put more than one checkmark on a scale.
4. Each time you complete a rating, check the box of your choice to the right of the scale.

Overall Rating of the Room Environment

One scale is provided for you to give an overall rating to the environment of this room. Complete this rating last. It is important that you consider only the six elements you have just rated as you develop your response to this scale. Do not allow any other factors to influence your evaluation.

Questions on Having a Cold and Smoking

After you have completed all of your ratings, please answer Question 1 and the appropriate part of Question 2. They are at the bottom of the Evaluation Sheet.

FIGURE 4-9b: VISITORS EVALUATION SHEET AND INSTRUCTIONS

Day Number ____________ Date ____________ Time ____________ Room Number ____________

EVALUATION SHEET

Rating of Individual Elements of the Room Environment	Acceptable	Unacceptable
Cold ___:___:___:___:___:___:___:___:___ Hot	☐	☐
Humid ___:___:___:___:___:___:___:___:___ Dry	☐	☐
Drafty ___:___:___:___:___:___:___:___:___ Stuffy	☐	☐
Stale ___:___:___:___:___:___:___:___:___ Fresh	☐	☐
No odor ___:___:___:___:___:___:___:___:___ Strong odor	☐	☐
Loud noise ___:___:___:___:___:___:___:___:___ No noise	☐	☐

Overall Rating of the Room Environment

Comfortable ___:___:___:___:___:___:___:___:___ Uncomfortable

1. Do you have a cold today?

   Yes ☐ No ☐

2a. If you are a smoker, about how many hours ago today did you have your last smoke?

   _____ hours ago today

2b. If you are not a smoker or if you did not smoke today, check this box . . . . ☐

FIGURE 4-9c: VISITORS EVALUATION SHEET AND INSTRUCTIONS

Name ______________________ Date ____________

Room Number ____________
Row/Table ______ Seat ______
Time Completed ____________

HOW THE AIR FEELS TO ME

Instructions: Read each of the following items along with your teacher, then put a checkmark ☑ in the box under the answer you feel is best.

---

1. TEMPERATURE

Temperature is a measure of how hot or how cold the air is. Think about the air in this classroom.

Do you feel the air is

Too COLD	COLD, but not too COLD	Neither COLD nor HOT	HOT, but not too HOT	Too HOT	Don't know
☐	☐	☐	☐	☐	☐

2. HUMIDITY

Humidity is a measure of how damp or how dry the air is. Think about the air in this classroom.

Do you feel the air is

Too DAMP	DAMP, but not too DAMP	Neither DAMP nor DRY	DRY, but not too DRY	Too DRY	Don't know
☐	☐	☐	☐	☐	☐

3. MOVEMENT OF THE AIR

If we feel the air is moving by us as we sit very still, we can say that the room is "drafty." If we do not feel the air moving, but wish that it would move, we can say that the room is "stuffy." Think about the air in this classroom.

Do you feel this classroom is

Too DRAFTY	DRAFTY, but not too DRAFTY	Neither DRAFTY nor STUFFY	STUFFY, but not too STUFFY	Too STUFFY	Don't know
☐	☐	☐	☐	☐	☐

4. THE KIND OF AIR

By the "kind of air" we mean how fresh or how stale the air is. If we think there is plenty of clean air in the room from the outside, we can say that the air in the room is "fresh." If we think there is not enough clean air in the room from the outside, we can say that the air in the room is "stale." Think about the air in this classroom.

Do you think the air is

STALE	Neither STALE nor FRESH	FRESH	Don't know
☐	☐	☐	☐

5. SMELL

Do you think the air in this classroom has

No SMELL	A SMELL, but not a bad SMELL	A bad SMELL	Don't know
☐	☐	☐	☐

FIGURE 4-10a: STUDENT QUESTIONNAIRE

6. NOISE

Listen for noise caused by the air in this classroom.

Do you think the air in this classroom has

Too much NOISE	NOISE, but not too much NOISE	No NOISE	Don't know
☐	☐	☐	☐

7. COMFORT

Do you feel the air in this classroom is

Very COMFORTABLE	COMFORTABLE	Neither COMFORTABLE nor UNCOMFORTABLE	UNCOMFORTABLE	Very UNCOMFORTABLE	Don't know
☐	☐	☐	☐	☐	☐

8. A COLD

Do you have a cold today?

Yes	No	Don't know
☐	☐	☐

FIGURE 4-10b: STUDENT QUESTIONNAIRE

evaluate and may present less of an obstacle for them to get started. Third, the scales preceding the odor scale seem to prepare the way for a question on odor. "Stale" vs. "Fresh" was added to obtain additional information on the quality of the room air. It was felt that the other scales could not be interpreted to get these data. "Loud noise" vs. "No noise" was substituted for "Quiet" vs. "Noisy." This provided parallel construction with the question on odor and was expected to help determine whether the respondents understood how to mark the unipolar scale on odors.

The "Comfortable" vs. "Uncomfortable" scale was added to obtain an overall rating of the room environment. The instructions tell the respondents that "it is important that you consider only the six elements you have just rated as you develop your response to this scale". This scale was intended not only for the purpose just stated, but also to provide an indication of the order of importance of the six elements to the respondents.

The questions at the bottom of the Evaluation Sheet were added to identify persons with colds and to determine how many hours ago the respondents smoked. Data collected from persons with colds could be excluded from the analysis. However, no exclusions were made in developing the results presented in this report because the number of observations were too few to permit exclusions.

It is not known exactly how much smoking effects the sense of smell. The feeling among many investigators is that its effect is slight and may reduce sensitivity to certain odors, but not all odors. Because the complex of odors expected to be encountered in schools, hospitals, and office buildings cannot be completely characterized, the question on smoking was added. Data from the smokers were not excluded, however, for the same reason that data from persons with colds were not excluded.

o <u>HOW THE AIR FEELS TO ME</u>

Figure 4-10 shows the Evaluation Sheet completed by the children at Fairmoor Elementary School in Columbus, Ohio, and at Oakland Garden Elementary School in Bayside, New York. The form was designed to obtain the same type of information as the Evaluation Sheet completed by adult respondents. The major difference is that the "Acceptable" vs. "Unacceptable" choices are incorporated into the scales themselves. The format evolved from discussions with an education psychologist and others on the staff of the San Diego Unified School

District who are familiar with the techniques of communicating with children. A five page set of instructions was prepared for the teacher to read to the children while the children were pretested in the third grade of an elementary school in San Diego, California.

5.0 DISCUSSION OF RESULTS

Generally, perceived odor intensity and threshold detectability levels were found to be very low in most of the schools, hospitals, and office areas included in this odor study. Mean intensity measurements for both existing and reduced ventilation conditions fell between 2.0 to 4.0 on the butanol scale and between 5 and 15 (ED_{50}) for the threshold detectability, with standard errors of ± 0.3 and ± 1.5 respectively. Exceptions were the San Francisco office building (ED_{50} = 18) and the East Coast hospital administrative areas (ED_{50} = 27). These buildings had smoking either directly in or adjacent to the test areas.

In the following sections, the varied ventilation studies and the existing conditions are summarized and discussed. The data are presented in histographic fashion relating the median of daily mean values of odor detectability and intensity with each ventilation condition. Appendices A thru D contain the daily measurement data for sensory odor, ventilation, chemical, and questionnaire responses respectively.

5.1 Primary Experiments

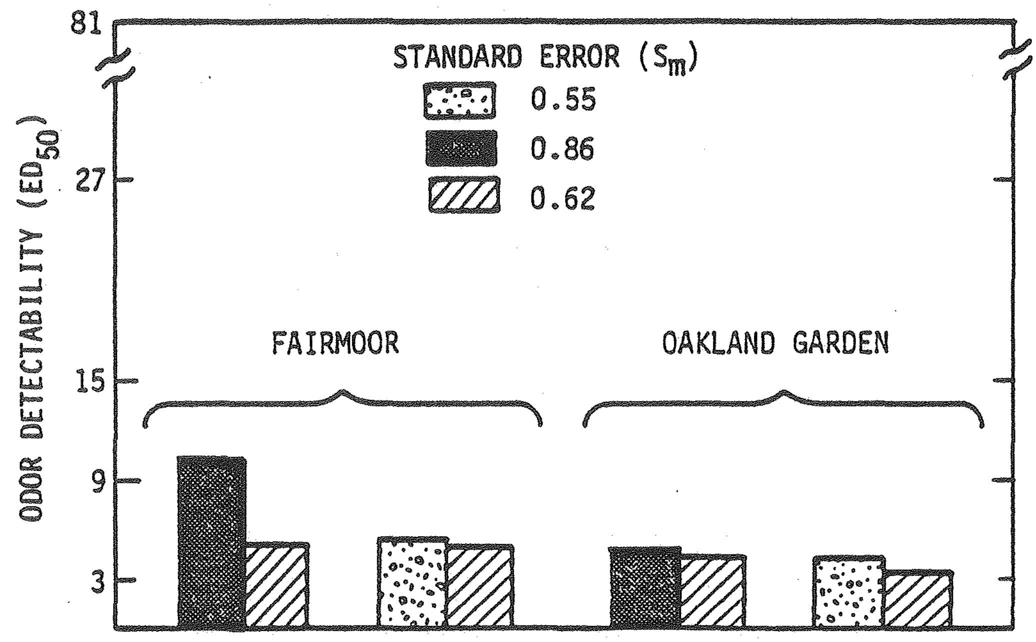
The results of the sensory odor measurements for the four buildings in which the ventilation was varied are summarized in Figures 5-1, 5-2, and 5-3. In interpreting these results it must be recognized that the Tedlar bags produced a 'background' or system odor that we were unable to eliminate. This amounted to a mean value of 2.0 for detectability with a standard deviation, σ of 1.0. The comparable values for intensity are a mean of 1.0 with a σ of 0.4.

The values plotted in these Figures represent the median of daily mean values obtained for each ventilation condition. All mean values are within one scale unit of either parameter, detectability (ED_{50}) or intensity. The standard errors for various buildings and parameters are shown on the appropriate figures.

o SCHOOLS

Both elementary schools studied exhibited low odor levels, in terms of intensity and ED_{50}, under both normal and reduced ventilation rates. The normal ventilation rates at both schools were at or below the minimum ventilation requirement per occupant as recommended in ASHRAE Standard 62-73, shown

SCHOOLS			
VENTILATION (CFM/PERSON)	NORMAL	REDUCED	LEGEND
FAIRMOOR ELEMENTARY	14.0	6.7	NORMAL VENTILATION
OAKLAND GARDEN	7.6	1.4	REDUCED VENTILATION
AIR CHANGES/HR.			OUTSIDE AIR
FAIRMOOR ELEMENTARY	2.1	1.1	
OAKLAND GARDEN	2.2	0.4	



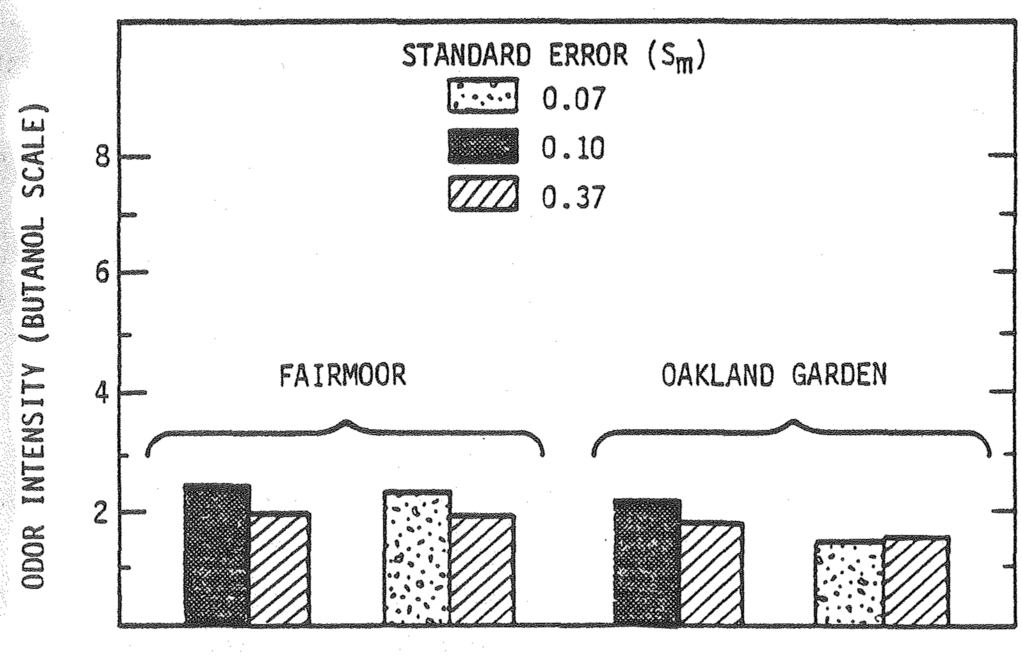
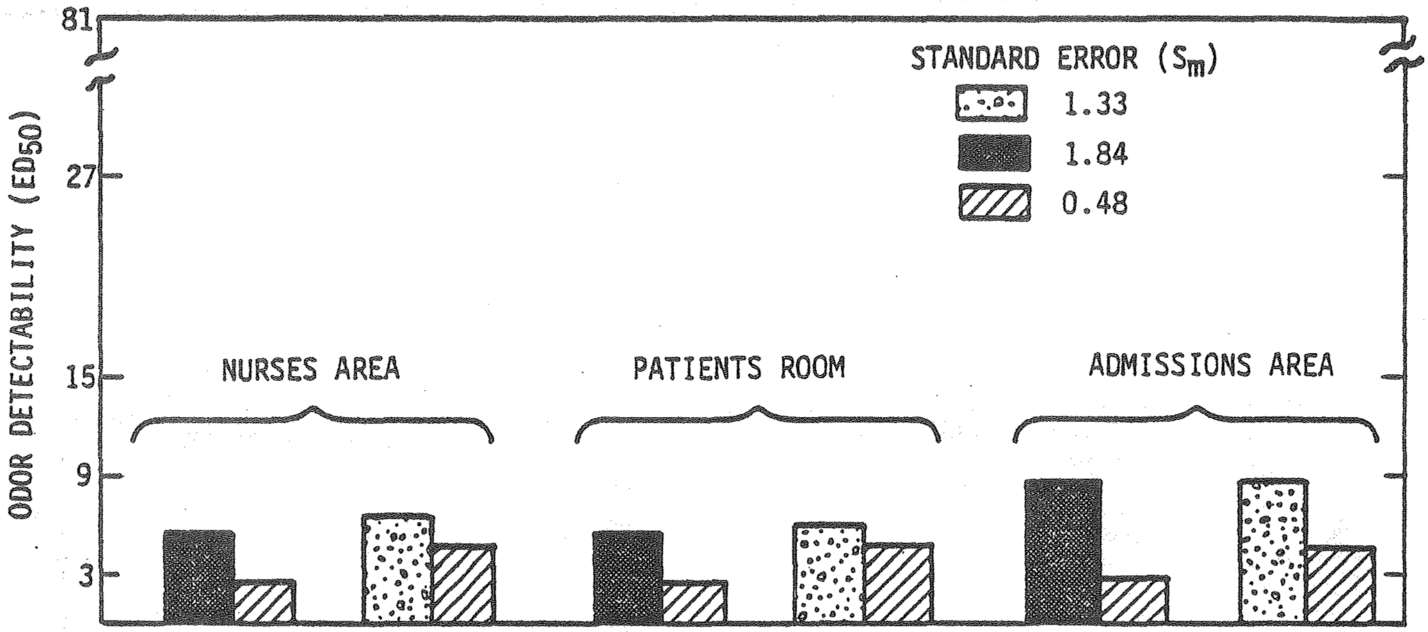


FIGURE 5-1: SCHOOL VARIABLE VENTILATION/ODOR RELATION

HOSPITAL			
VENTILATION (CFM/PERSON)	NORMAL	REDUCED	LEGEND
NURSES AREA	65	27	NORMAL VENTILATION
PATIENTS ROOM	101	79	REDUCED VENTILATION
ADMISSIONS AREA	164	75	OUTSIDE AIR
AIR CHANGES/HR.			
NURSES AREA	6.5	2.7	
PATIENTS ROOM	5.2	4.1	
ADMISSIONS AREA	6.1	2.8	



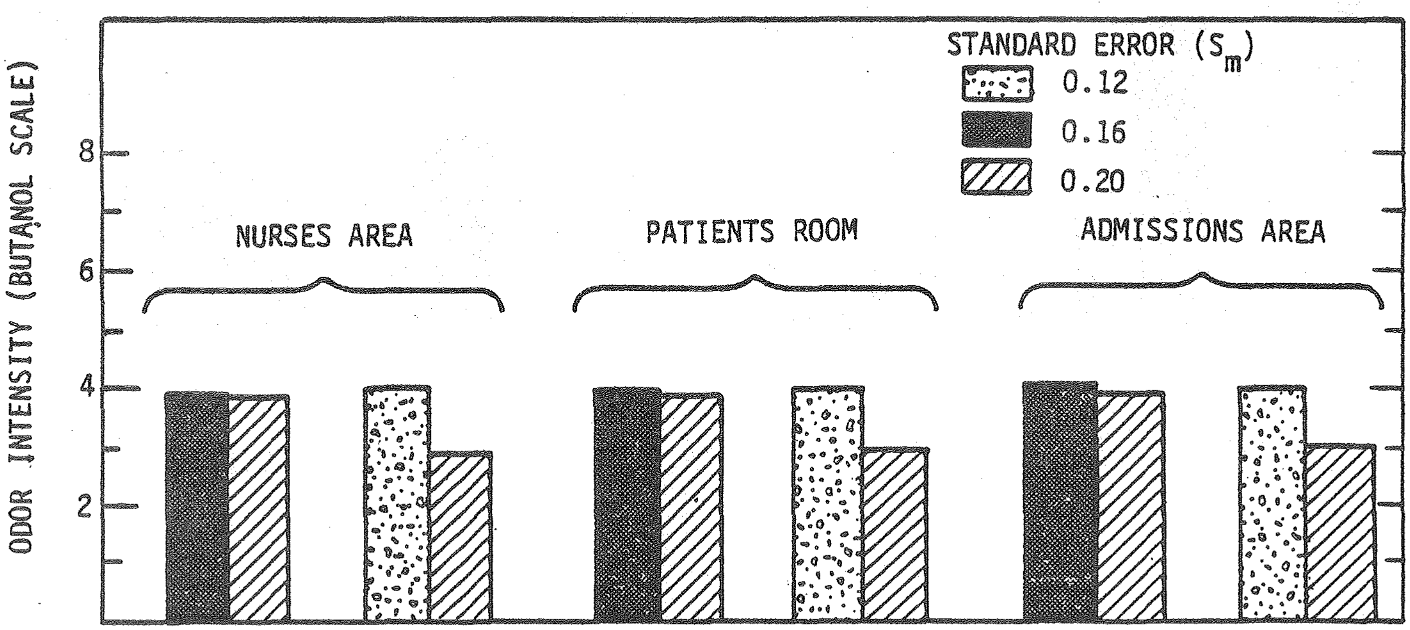


FIGURE 5-2: HOSPITAL VARIABLE VENTILATION/ODOR RELATION

OFFICE BUILDING			
VENTILATION (CFM/PERSON)	NORMAL	REDUCED	LEGEND
INTERVIEW AREA	17.5	4.6	NORMAL VENTILATION
AIR CHANGES/HR.			REDUCED VENTILATION
INTERVIEW AREA	2.3	0.6	OUTSIDE AIR

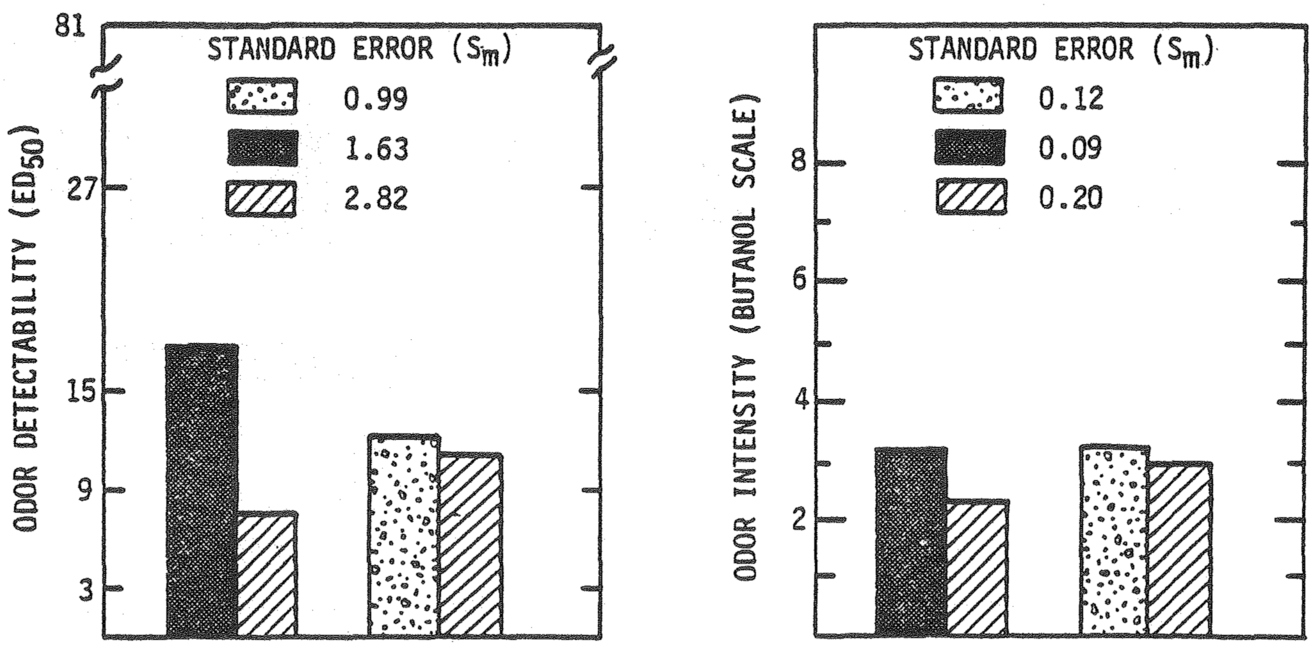


FIGURE 5-3: SAN FRANCISCO OFFICE BUILDING VARIABLE VENTILATION/ODOR RELATION

in Table 5-1. As shown in Figure 5-1, reducing the ventilation rate in the classrooms by a factor of two at the Fairmoor School produced a change of intensity of only 0.1, not a significant difference. A twofold increase in detectability occurred. However, at the Oakland Garden School a fivefold reduction in ventilation to 1.4 cfm per person produced almost no change in detectability and an increase in intensity which, while statistically significant, still was very low.

The chemical data for these buildings correlate very well with ventilation changes. As the ventilation rate decreased by a factor of two, the organic concentration increased by a factor of 2.1 (Table 5-2). However, under no ventilation condition was the concentration of any specific odorant found to be above its threshold concentration by the GC/odorogram technique even at a ventilation rate of 1.4 cfm per person. Yet, there was odor detectable in the buildings. Prior work at IITRI has shown that in cases where none of the components appears to be present above its odor threshold concentration, many such components together may build up to a perceptible odor. In the classrooms the odor quality would be described as "occupancy" and "musty (library)". In the corridors, there were occasional cooking odors detectable, emanating from the cafeterias.

o HOSPITAL

The hospital results shown in Figure 5-2 are most remarkable for the extraordinary ventilation rates found at this facility and the high intensity values found for outside air. The outside air samples were taken in the parking lot immediately outside the Admissions area where the mobile odor laboratory was located. Weather conditions were rainy and cool (50-55^{o}F) almost the entire time. Although odors were not noticeable in the outside air while one stood in the parking lot, an odor characterized by pungent, acrid notes was readily detectable in undiluted bag samples. This undiluted odor was judged to be between 3.0 and 4.0 on the butanol scale. However, upon a threefold dilution with odorfree (carbon purified) air the odor became almost undetectable as shown in Figure 5-2.

These results show that a twofold decrease in ventilation produced no discernible change in odor intensity or detectability in any of the three areas. This may be partially attributed to the very high ventilation rate, i.e., three times standard used with reduced ventilation, and partially to the observed substantial infiltration from adjacent areas within the building.

TABLE 5-1

VENTILATION REQUIREMENTS PER OCCUPANT
RECOMMENDED IN ASHRAE STANDARD 62-73

	Minimum	Recommended
Classrooms	10 CFM (5 L/S)	10-15 CFM (5-7.5 L/S)
School Libraries	7 CFM (3.5 L/S)	10-12 CFM (5-6 L/S)
Hospital Wards	10 CFM (5 L/S)	15-20 CFM (7.5 L/S)
Nurse/Hallways	20 CFM (10 L/S)	25-30 CFM (12.5-15 L/S)
Laboratories	15 CFM (7.5 L/S)	20-25 CFM (10-12.5 L/S)
General Office Space	15 CFM (7.5 L/S)	15-25 CFM (7.5-12.5 L/S)
Waiting Lounges	10 CFM (5 L/S)	15-20 CFM (7.5-10 L/S)
Conference Rooms	25 CFM (12.5 L/S)	30-40 CFM (15-20L/S)

TABLE 5-2

SCHOOL CHEMICAL DATA
VARIED VENTILATION

Location	Total Integrator Counts	Hydrocarbon Content ($\mu g/m^3$)
Room 20 - normal	2,816,429	247.3
reduced	6,057,373	531.9
Gym - normal	2,836,237	249.0
- reduced	8,222,500	722.0
Room 12 - normal	9,825,374	862.7
- reduced	(sample lost)	-----

*Based on response of dodecane.

As with the schools, the organic content of the air, however, shows a direct correlation to ventilation. Table 5-3 summarizes the chemical loading results obtained at this facility. Again, no single odorant was found to be above its detection threshold.

Total organic material collected during reduced ventilation exhibited a factor of 2.2 times the loading during normal ventilation. The nanogram level of this material ranges from 1324 $\mu g/m^3$ down to 280 $\mu g/m^3$. The highest amount was found in the patient area. Major compounds identified by GC/MS for the patient/nurse areas included ethanol, butene, methyl propene, acetone, isopropanol, 2-methyl-1, 3-butadiene, benzene, ethyl benzene, 1,1,1-trichloroethane, toluene, and xylene. The only major compounds identified in the admissions area were isopropanol and acetone.

o <u>OFFICE BUILDING</u>

The San Francisco office building exhibited higher odor levels than either school or the hospital. (The building had been selected partially because of complaints of indoor air quality.) As shown in Figure 5-3, a 75% reduction in ventilation resulted in no change in perceived odor intensity because of the increased odor of the outside air. In terms of odor detectability, however, there was a 50% increase with the reduced ventilation.

Odor quality of inside air was characteristic of tobacco smoke and occupancy. These results indicate the influence of tobacco smoke on odor intensity and detectability. Panelists recognized only the tobacco smoke character and not the "occupancy" note also detectable in the building. Aside from the admissions/waiting areas of some of the hospitals, this was the only building where considerable tobacco smoke was present. The number of smokers and population density was much greater in this building than in the hospital admissions area.

The fresh air intake was located near ground level adjacent to multiple odor sources, including a garbage dumpster, sewer vent and idling vehicles. Odor characteristics of outside air reflected these sources, especially with normal ventilation conditions. GC/odorgram traces, Figures 5-4, 5-5, and 5-6 illustrate the indoor-outdoor chemical similarities and the increased loading under reduced ventilation conditions.

TABLE 5-3

RESULTS OF ODOROGRAM ANALYSIS
OF UCONN MEDICAL CLINIC

Total Sampler No.	Description	Hydrocarbon Total Integrator Counts	Hydrocarbon Content ($\mu g/m^3$)
#130	Admissions, AM	3,184,696	279.6
#160	Admissions, PM	3,392,344	297.9
#157	Admissions, AM, Reduced	7,284,458	639.6
#148	Admissions, PM, Reduced	7,202,265	632.4
#138	Nurses Station, AM	5,647,697	495.9
#158	Nurses Station, PM	4,576,160	401.8
#146	Nurses Station, AM, Reduced	11,203,750	983.4
#155	Nurses Station, PM, Reduced	9,793,200	859.8
#135	Patients Rm 2116, AM	2,816,870	247.3
#159	Patients Rm 2116, PM	9,059,260	795.4
#149	Patients Rm 2116, AM, Reduced	15,074,900	1323.6
#137	Patients Rm 216, PM, Reduced	13,174,643	1156.7

*Based on response of dodecane.

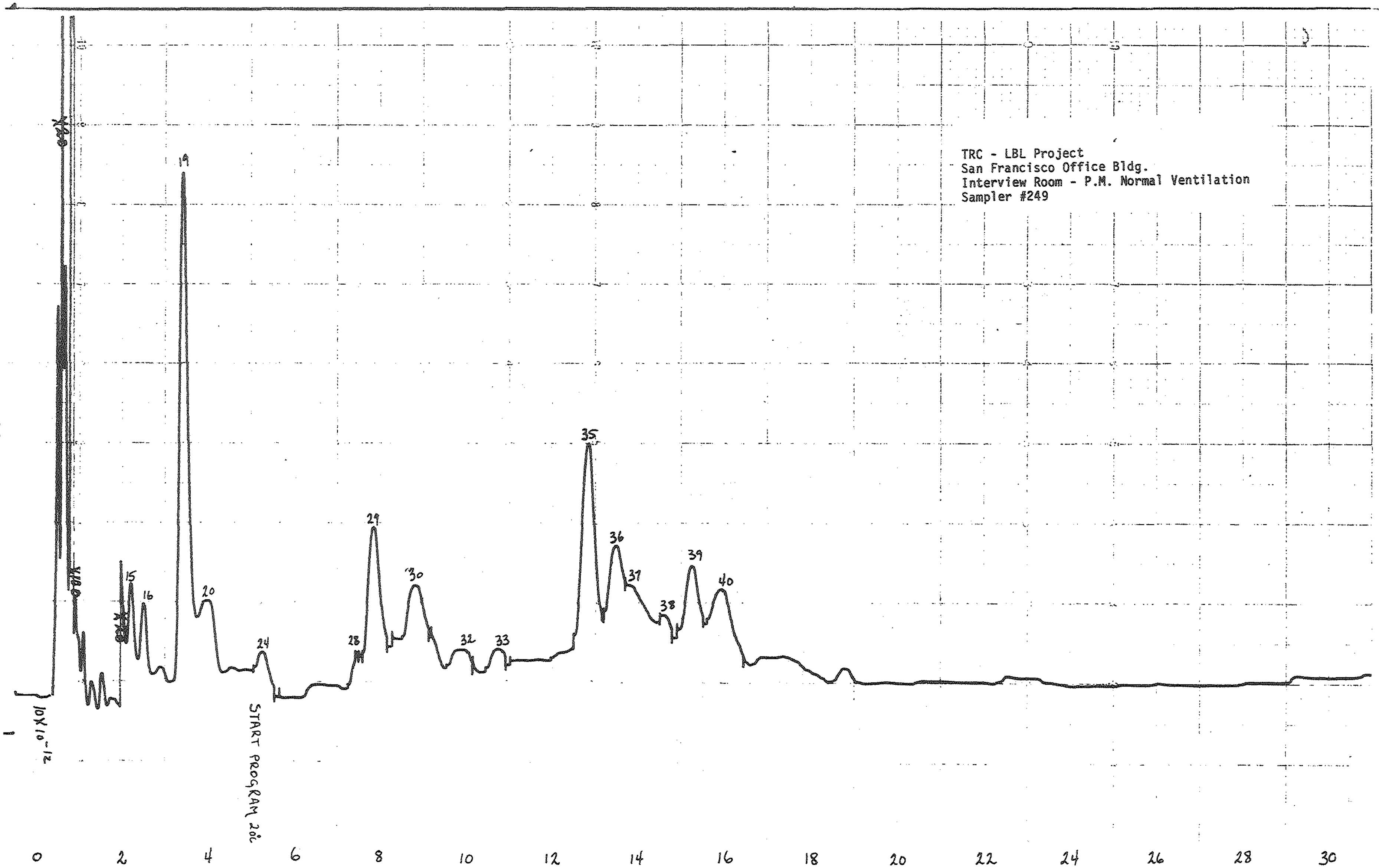


Figure 5-4: GC/odorgram of Interview Room-PM: Normal Ventilation

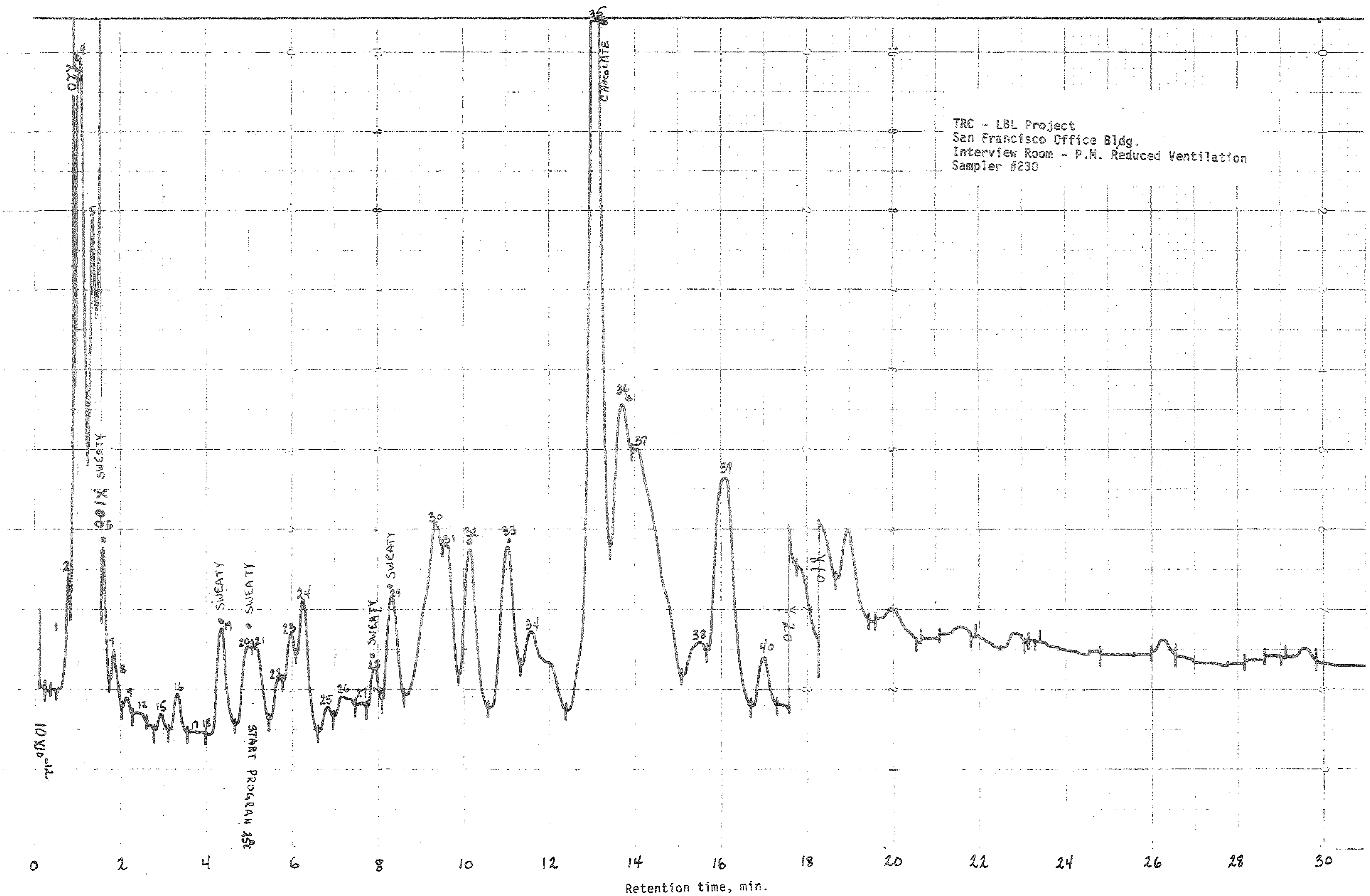


Figure 5-5: GC/odorogram of Interview Room-PM: Reduced ventilation

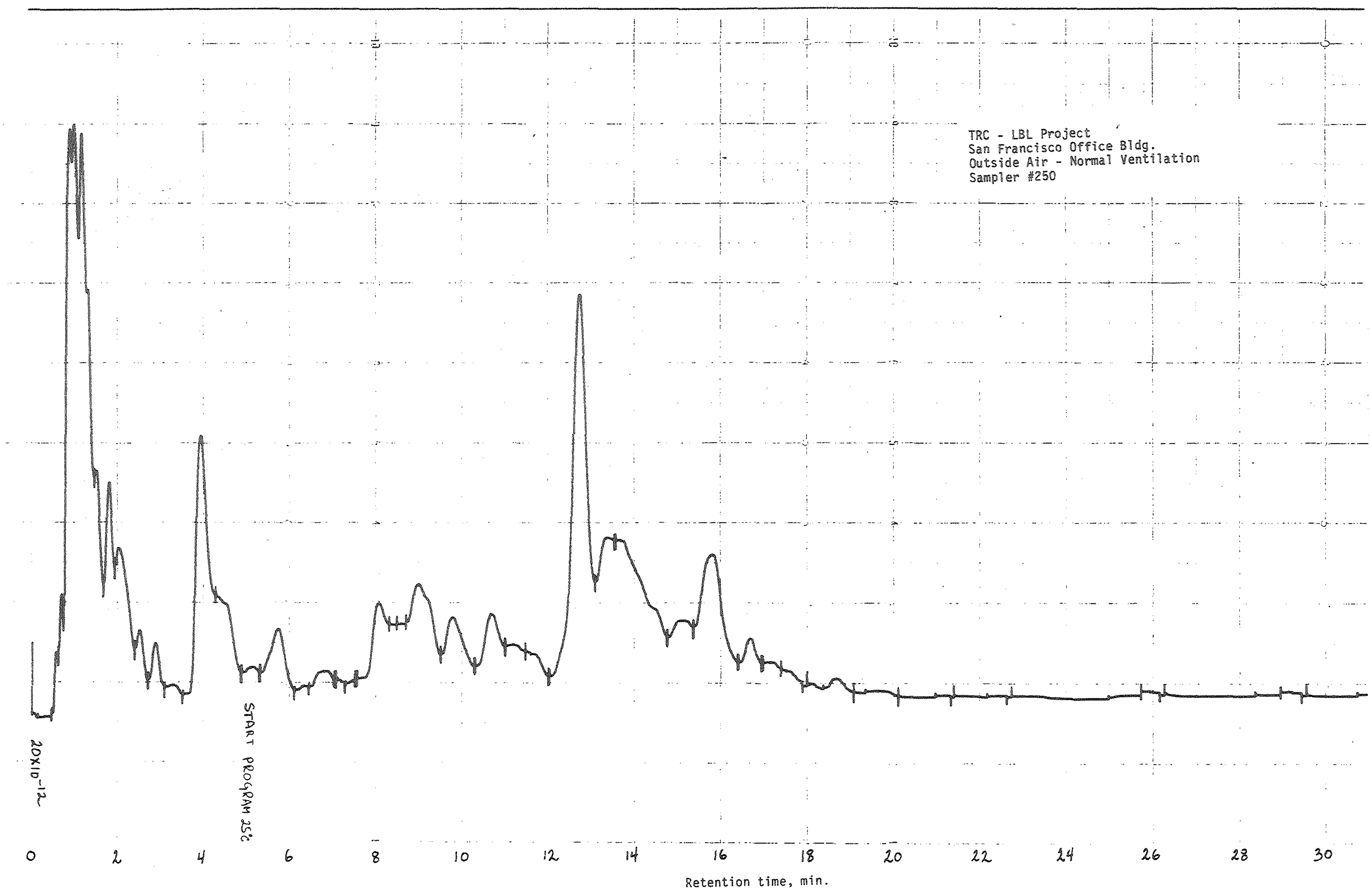


Figure 5-6: GC/odorogram of outside air at ventilation intake

This building is the only one in which the concentration of individual odorants exceeded their threshold concentrations. Some 39 compounds were identified with reduced ventilation, 9 of which were found to be odorous (note Tables 5-4 and 5-5). The odorous peaks included: benzene, toluene (the most intense), 2-ethyl 1-butanol, trimethyl cyclohexane, xylene, n-nonane, 2-methyl nonane, and 2,2,4-trimethyl heptane. In some cases, the GC peak may correspond to several unresolved substances, and the odor may be that of a minor impurity, not of the principal component of the peak. Such may be the case with odorous peaks identified as n-alkanes which by themselves have little if any odor. Twelve of the 39 peaks were also found in the outside air, including the three odorous peaks associated with the aromatics, benzene, toluene and xylene. The average hydrocarbon concentration under reduced ventilation (4.6 cfm/person) was 1627 $\pm$ 26 $\mu g/m^3$, while under normal ventilation (17.5 cfm/person) the concentration was 364 $\pm$ 40 $\mu g/m^3$ (note Table 5-6). As with the other buildings, the reduction in total hydrocarbon concentration is directly proportional to the ventilation rate.

o ACCEPTABILITY

The results of the CIC questionnaire surveys regarding the odor acceptability portion for each primary site are summarized in Table 5-7. Appendices D-1, D-2, and D-3 present in detail the collection procedures and analyses of all the questionnaire data as compiled by Mr. R. David Flesh of Copley International Corporation. In general, the results of the two schools exhibit the expected difference between adapted subjects and visitors. A t-test-by-difference of odor scale readings for 20 rating pairs of occupants and visitors was done. The mean difference was by 1.3 scale units-odor felt stronger by visitors. The value of t was 4.15 indicating that this result was significant at $p<0.001$ level. However, the relation between odor intensity and acceptability was surprising, with low comparative butanol intensities of 2.6 or less being judged as acceptable by less than 70% of the visitors.

In the other two buildings, the results are even more unexpected. The adapted group (occupants) and visitors (panelists) both exhibit the same perceived odor scale ratings. With butanol intensity ratings between 3.3 and 4.2, visitor acceptability in these two buildings exceeded 88%. These odor levels, however, were acceptable to less than 70% of the building occupants. In both buildings employees had complained about air quality, and these results may reflect the reactions of sensitized groups.

Table 5.4

GC/Mass Spec. Results of Office Building Interview Room-Reduced Ventilation

GC/Odorogram Peak Number	Formula	Compound Name	#251-PM: 9/21		#230-PM: 9/19		#253-AM: 9/21	
			Integrated Area	Conc. μg/m³	Integrated Area	Conc. μg/m³	Integrated Area	Conc. μg/m³
1			148	0.01	498	0.04		
2			208	0.02	13,140	1.15		
3			147	0.01	140,400	12.33		
4			5,913	0.52	168,300	14.78		
5*			7,509	0.66	142,000	12.47		
6* +	C_6H_6	Benzene	307,800	27.03	343,200	30.13		
7	C_7H_{16}	2-Methyl Hexane	105,900	9.30	202,600	17.79		
8			36,880	3.24	1,033	0.09		
9	C_7H_{16}	3-Methyl Hexane	135,600	11.91	113,300	9.95		
10			117,700	10.33	920	0.08		
11			89,180	7.83				
12	C_2HCl_3	Trichloroethylene	106,800	9.83	117,100	10.28		
13	C_7H_{14}	Alkene	45,830	4.02	1,358	0.12		
14			582	0.05	45,890	4.03		
15 +	C_7H_{16}	n-Heptane	80,890	7.20	101,200	8.89	54,220	4.76
16 +	C_7H_{14}	Methyl Cyclohexane	94,560	8.30	157,900	13.86	72,520	6.47
17	C_7H_{14}	Methyl Alkyl Cyclopentane	676	0.06	1,754	0.15	19,930	1.75
18 +	C_7H_{14}	Methyl Alkyl Cyclopentane	53,980	4.74	90,470	7.94	32,590	2.86
19* +	C_7H_8	Toluene	315,800	27.73	366,100	32.14	239,200	21.00
20*	$C_6H_{14}O$	2-Ethyl-1-Butanol	261,900	23.00	277,200	24.34	443,100	38.90
21	C_8H_{18}	Alkane	241,300	22.06	264,000	23.18		
22	C_8H_{16}	Dimethyl Cyclohexane	145,900	12.81	180,500	15.85	1,311	0.12
23 +	C_8H_{18}	Alkane	369,800	32.47	270,900	23.79		
24 +	C_8H_{18}	n-Octane and	418,900	36.78	400,900	35.19	768,700	67.49
+	C_2Cl_4	Tetrachloro Ethylene						
25	C_9H_{20}	2,4-Dimethyl-3-Ethyl Pentane	112,200	9.85	128,200	11.26	474,100	41.63
26	C_9H_{18}	Alkyl Cyclohexane	152,600	13.40	246,400	21.63	127,600	11.20
27	C_9H_{20}	Alkane and	114,900	10.09	121,400	10.66	160,300	14.07
	C_9H_{18}	Cycloalkane						
28*	C_9H_{18}	Trimethyl Cyclohexane	219,600	19.28	229,800	20.18	227,200	19.95
29* +	C_8H_{10}	Xylene	504,200	44.27	501,200	44.01	606,000	53.21
30	C_9H_{20}	2,2,3-Trimethyl Hexane or	1,148,000	100.79	1,152,000	101.15	1,006,000	88.33
		2,2,5-Trimethyl Hexane or						
		2,2,3,4-Tetramethyl Pentane or						
		2,2-Dimethyl-3-Ethyl Pentane						
31	C_9H_{20}	2,2,5-Trimethyl Hexnae	493,200	43.30	529,300	46.47	790,000	69.36
		2,2,3-Trimethyl Hexane						
		2,2-Dimethyl-3-Ethyl Pentane						
		2,2-Dimethyl Heptane						
		2,2,3,4-Tetramethyl Pentane						
32*	C_9H_{20}	n-Nonane	715,500	62.82	724,800	63.64	814,100	71.48
33*	$C_{10}H_{22}$	2-Methyl Nonane	825,800	72.51	821,100	72.09	354,600	31.13
34 +	$C_{10}H_{22}$	Alkane	588,000	51.63	822,200	72.19	868,600	76.26
35*	$C_{10}H_{22}$	2,2,4-Trimethyl Heptane	2,892,000	253.92	3,106,000		3,527,000	
36	$C_{10}H_{22}$	Alkane	3,061,000	268.76	1,341,000		3,564,000	
37	$C_{10}H_{22}$	Alkane			2,019,000			
38	$C_{10}H_{22}$	Alkane	445,600	39.12	525,200		494,800	
39 +	$C_{10}H_{12}$	Alkyl Benzene	1,198,000	105.18	1,463,000		1,282,000	
	C_9H_{10}	Methyl Styrene or Indane						

*Indicates Odorous Peaks.

+Found both inside and outside.

TABLE 5-5

OFFICE BUILDING - REDUCED VENTILATION
ODORS FOUND IN INTERVIEW ROOM

GC/Odorogram Peak Number	Sample Number 251	230	253
6	Sweaty	Sweaty	
19	Sweaty	Sweaty	Sweaty
20	Sweaty	Sweaty	Sweaty
28	Odor*	Sweaty	Odor*
29	Odor*	Sweaty	Sweaty
32	Sweaty	Odor*	Odor*
33	Sweaty	Odor*	Sweaty
35	Chocolate	Chocolate	Chocolate

*Odor not recognizable.

TABLE 5-6

RESULTS OF GC-ODOROGRAM ANALYSIS OF INTERVIEW ROOM
REDUCED VENTILATION

Sample Number	Sampled	Analyzed	Integrated Area	Concentration, $\mu g/m^3$
AM Samples				
252	9/19	10/12	Sample was Lost	
253	9/21	10/4	18,749,098	1646
PM Samples				
230	9/19	10/10	18,197,602	1598
251	9/21	10/4	18,660,000	1638

RESULTS OF GC-ODOROGRAM ANALYSIS OF INTERVIEW ROOM
NORMAL VENTILATION

Sample Number	Sampled	Analyzed	Integrated Area	Concentration, $\mu g/m^3$
AM Samples				
231	9/26	10/16	3,909,238	343
246	9/28	10/15	7,674,587	674
PM Samples				
249	9/25	11/20	4,656,419	409
233	9/26	10/16	3,446,125	303
232	9/28	10/15	1,045,000	92

TABLE 5-7

SUMMARY OF ODOR ACCEPTABILITY, CATEGORY SCALE RATING AND INTENSITY FOR VARIABLE VENTILATION STUDY

	NORMAL VENTILATION						REDUCED VENTILATION			
	PANELISTS		OCCUPANTS		Mean Sensory Intensity (Butanol)		PANELISTS		OCCUPANTS	
Site and Location	Odor Scale* 1-9	Accept. %	Odor Scale* 1-9	Accept. %	N	R	Odor Scale 1-9	Accept. %	Odor Scale 1-9	Accept. %
Fairmoor School										
Room 12	4.6	77	4.1	-	2.4	2.4	5.3	55	3.8	-
Room 20	4.9	68	3.3	-	2.5	2.6	6.0	56	3.2	-
Room 21 (control)	5.9	41	3.5	-	-	-	5.8	52	2.6	-
Gym	3.1	94	-	-	2.3	2.0	3.7	92	-	-
UConn Hospital										
Admissions	5.2	91	5.2	64	4.1	4.2	5.0	96	5.7	56
Nurses' Station	5.5	77	4.8	79	3.9	4.0	5.2	90	5.5	56
Patient Room	4.5	93	5.2	76	4.0	3.9	5.0	88	5.0	68
San Francisco Office Bldg.										
Applicant Room	5.7	81	5.9	57	3.1	3.3	5.8	90	5.7	62
Oakland Garden School										
Room 323	4.5	82	2.6	-	1.7	2.3	5.0	68	1.9	-
Room 325	5.0	86	2.5	-	1.5	2.2	5.6	49	3.3	-
Room 322 (control)	4.6	75	3.1	-	-	2.2	5.9	51	2.7	-

*Odor Scale from questionnaire survey utilizing Category Scale of 1 through 9.

Some simple statistical tests were done in order to determine the significance of relations between measured quantities. The results of those tests are capsulized below:

- Question: Are the odor scale (1-9) and odor acceptability ratings, both by panelists, correlated?

  Answer: (Acceptability %) = 147 - 14.2 (Odor Scale Scores)
  Correlation coefficient = 0.59
  Statistically significant, $p<0.01$

- Question: Are odor scores by panelists correlated to odor scores by occupants?

  Answer: No, correlation almost non-existent. Thus, beyond observation that occupants tend to give lower scores, the scores by panelists cannot be used to predict scores by occupants; apparently the two groups use different criteria when scoring the intensity of indoor odors.

- Question: Are panelists' odor scores and odor acceptability percent related to the butanol scale intensities measured on bag samples?

  Answer: No.

- Question: How do the odor scores (1-9 scale), odor acceptabilities, and butanol scale intensities change when the ventilation rate is reduced (use t-test-by-difference)?

  Answer:
  (1) Panelists' odor scores increased, in average, by 0.4 scale units; $t = 2.67$, $p<0.05$.

  (2) Occupants' odor scores increased, in average, by 0.1 scale units; $t = 0.33$, insignificant.

  (3) Panelists' odor acceptability decreased, in average, by 7%; $t = 1.36$; statistically insignificant.

  (4) Butanol scale readings increased, in average, by 0.16 scale steps; $t = 1.47$, insignificant. On the basis of properties of the butanol scale, this would correspond to about a 10% increase in the perceived odor intensities.

- Question: Do odor scores (1-9 scale) and odor acceptability percent relate to the butanol scale readings on bag samples?

  Answer: They do not relate. Even if all these indices changes in the expected direction when the ventilation rate was decreased, the direct scoring of the room odor may include additional sensory inputs such as odor character, feel of humidity, temperature-properties not measured by the butanol scale alone.

5.1.1 Overview of Findings

The results of all of the ventilation measurements and associated sensory odor and chemical analyses are summarized in Table 5-8. These results show that in elementary schools with no smoking, a ventilation rate of as little as 1.4 CFM/person or 0.4 air changes per hour does not have a significant effect on the detectability or intensity values obtained for grab samples evaluated off-site. As shown in Table 5-7, however, the same panelists tended to rate the odor strength slightly higher in the category scale with a slight decrease in acceptability when judging the odor directly in the classrooms with reduced ventilation. Concentration of organics varies almost directly with the ventilation rate in schools.

In the hospital, variations in detectability (ED_{50}) are proportional to ventilation changes but intensity ratings do not correlate with ventilation. Similar results are shown in Table 5-7 for the in-situ observations. Again, there is a direct variation of total organic concentration and ventilation rate. These results also show that this building is vastly over-ventilated. Even under reduced ventilation, the nurses' station is the only area which is even close to the code-specified rates. Yet, the organic concentrations are quite high, particularly in the patient room. The organic loading in the admissions area is comparable to that in the schools and office building. The higher chemical levels in the nurses' station and patient room are due to the extensive use of solvents for cleaning and disinfecting. In those areas, the odor of disinfectant was clearly recognizable.

In the San Francisco Social Services building, the reduction in ventilation rates was almost exactly proportional to the increases in detectability, intensity, and organic concentrations. The in situ evaluations, however, show essentially no difference for either occupants or visitors in the category ratings and acceptability judgments between the normal and reduced ventilation conditions.

5.2 Secondary Experiments

The results of the one day measurements at the 13 schools and hospitals are summarized in Figures 5-7 and 5-8. Schools are significantly less odorous than hospitals, averaging less than 3.0 on the butanol intensity scale, with ED_{50} values of 9 or less. Structural design, air conditioning, and outside temperature seem to have little effect on odor levels in classrooms, as the

TABLE 5-8

SUMMARY OF VENTILATION CHANGES, ODOR MEASUREMENTS, AND CHEMICAL CONCENTRATIONS

Building	Ventilation Rate CFM/Person Normal	Ventilation Rate CFM/Person Reduced	Ventilation Rate ACPH Normal	Ventilation Rate ACPH Reduced	Difference In Odor Detectability (ED_{50}) Inside-Outside Normal	Difference In Odor Detectability (ED_{50}) Inside-Outside Reduced	Difference In Odor Intensity (Butanol Scale) Inside-Outside Normal	Difference In Odor Intensity (Butanol Scale) Inside-Outside Reduced	Organic Concentration ($\mu g/m^3$) Normal	Organic Concentration ($\mu g/m^3$) Reduced
Fairmoor School	14.0	6.7	2.1	1.1	0.5	6	0.5	0.5	247.3	531.9
Oakland Garden School	7.6	1.4	2.2	0.4	1.0	0.2	0	0.8	-	-
UConn Medical Center										
Nurses Station	65	27	6.5	2.7	2	4	1.2	0	448.9	921.6
Patient Room	101	79	5.2	4.1	1	4	1.0	0.1	521.4	1240.2
Admissions	164	75	6.1	2.8	4	7	1.0	0.1	288.7	636.0
San Francisco Soc. Services	17.5	4.6	2.3	0.6	2	10	0.2	0.9	364	1627

AREAS	VENTILATION RATE (CFM/PERSON)	ACPH	LEGEND
CLASSROOMS	24.1	5.0	
SPECIALTY ROOMS	59.1	2.0	
PATIENT/NURSES	3.9	0.4	
LABORATORIES	173.4	10.7	
ADMISSIONS	34.4	5.3	
OUTSIDE AIR	—	—	

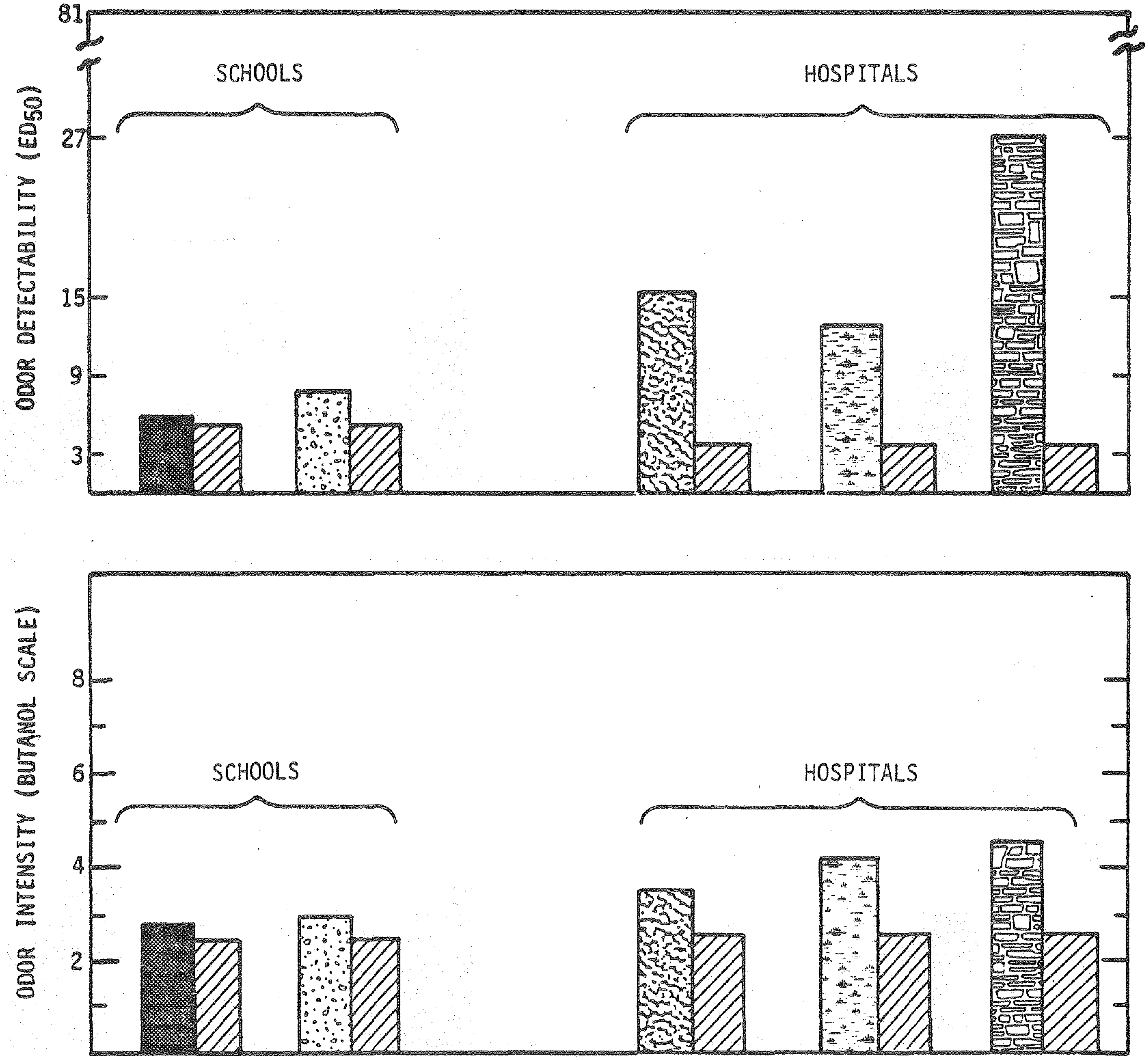
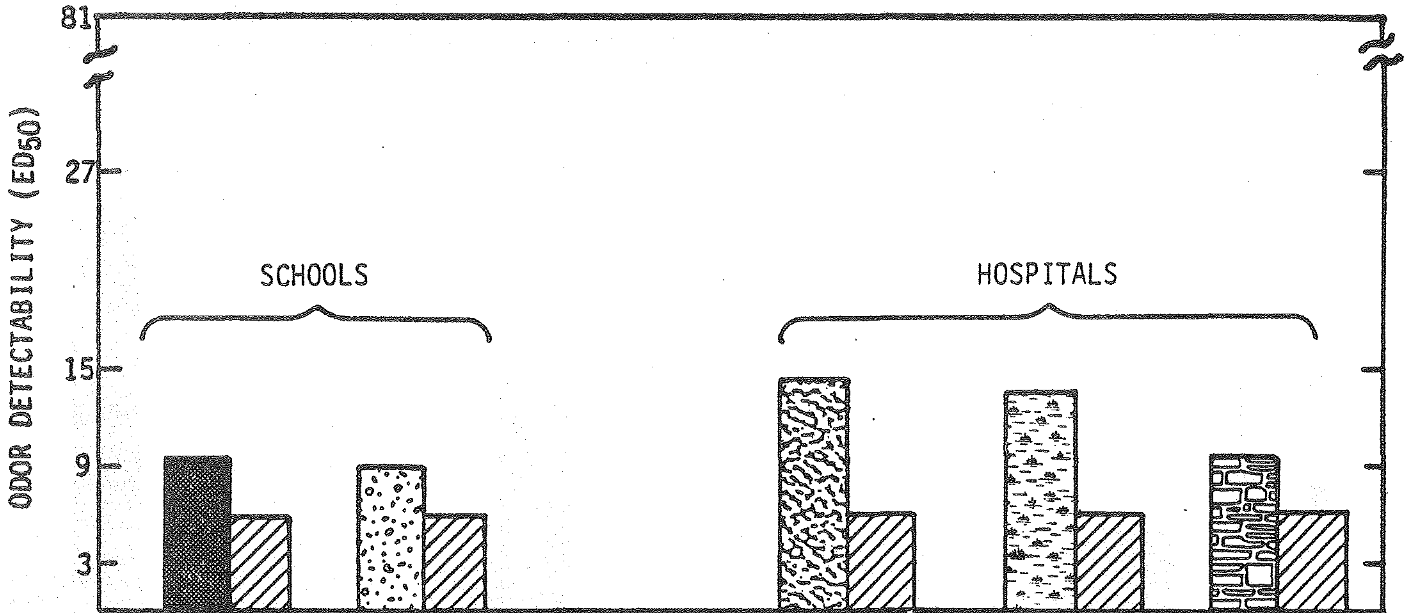


FIGURE 5-7: ODOR RELATION EAST COAST SCHOOLS & HOSPITALS

AREAS	VENTILATION RATE (CFM/PERSON)	ACPH	LEGEND
CLASSROOMS	23.5	5.6	
SPECIALTY ROOMS	166.7	3.5	
PATIENT/NURSES	56.9	4.8	
LABORATORIES	24.3	0.9	
ADMISSIONS	56.4	2.5	
OUTSIDE AIR	——	——	



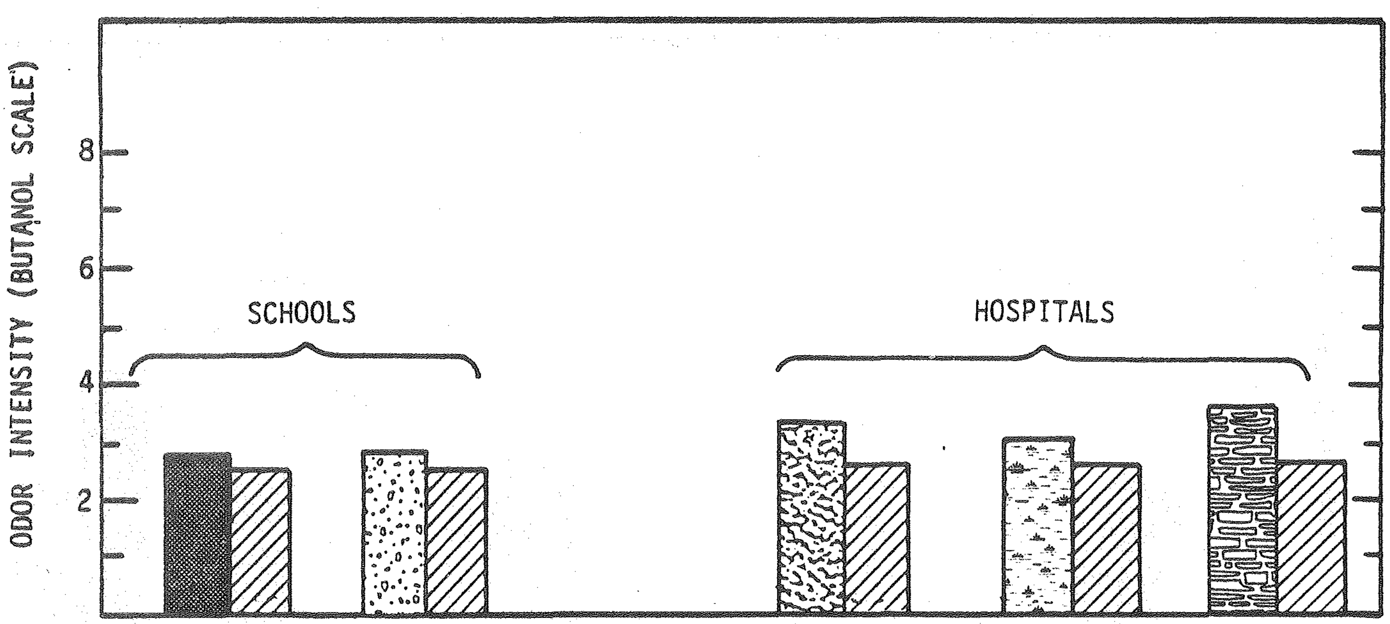


FIGURE 5-8: ODOR RELATION WEST COAST SCHOOLS & HOSPITALS

same results were obtained in schools in both areas with almost identical ventilation rates. Occupancy and building materials increase odor values above outside air by approximately one-half scale unit for both intensity and detectability.

Higher hospital odor levels are attributable primarily to the effect of tobacco smoke in these buildings. This is especially true of the admissions areas. In the Connecticut hospitals, smoking was allowed in the admissions areas and lobbies, and odor intensity averaged over 4.0 on the butanol scale and over 27 on the detectability, by far the highest value encountered in this study. This occurred in spite of fresh air ventilation rates of 34.4 cfm/person and 5.3 air changes per hour. In the Long Beach hospitals, however, smoking was not allowed in the lobbies in two buildings. In the other, there were few smokers present. Resulting odor levels were more than a full scale unit lower than in the Connecticut hospitals.

The effect of smoking and use of more odorous chemicals, i.e., solvents and disinfectants, in hospitals adds approximately a full scale unit above outside values for both intensity and detectability with present high ventilation rates.

The trend to energy conservation in the northeastern part of the country is reflected in the very low ventilation rates found in some of the patient/nurses areas in the Connecticut hospitals. Indeed, in one ward the ventilation system was on 100% recirculation, with fresh air being supplied by infiltration from other building areas when the ward door was open. In spite of an almost twentyfold lower ventilation rate in the patient/nurses area in the Connecticut hospitals, however, as compared to the Long Beach hospitals, odor levels were identical in both sets of buildings. The total organic material (chemical loading) was much higher in the Connecticut hospitals, with some odorants exceeding their threshold concentration at ventilation rates of 1.5 cfm/person (Appendix C).

The chemical data for the schools and hospitals are presented in Tables 5-9 and 5-10. The average classroom organic chemical loading was 233 $\mu g/m^3$ at an average ventilation rate of 19.2 cfm/person. Specialty rooms (i.e. art rooms), however, averaged considerably higher at 1757 $\mu g/m^3$, at a ventilation rate of 26.1 cfm/person. As with odor, organic concentrations were higher in hospitals averaging: 509 $\mu g/m^3$ at an average ventilation of 64.7 cfm/person for admission/waiting areas; 769 $\mu g/m^3$ for patient nursing

TABLE 5-9

SCHOOL CHEMICAL DATA SUMMARY
EXISTING VENTILATION

Site	Ventilation Rate (CFM/Person)	Air Changes Per Hour	Hydrocarbon Content ($\mu g/m^3$)	Odor Level (ED_{50})
Muir Room 18	47.2	9.7	102	9
Hudson Rooms 28/29	9.0	2.0	129	20
Hudson Rooms 27/30	5.9	1.3	194	10
Edison Room 5	29.0	4.8	70	8
LBPT Room 138	9.8	3.3	45	11
Emerson Room 3	19.9	3.2	59	4
Emerson Room 10	5.6	0.9	825	4
Silas Room 102	18.1	3.0	377	8
Silas Room 109	25.5	5.8	372	7
Webster Room 15	19.5	2.5	2052	13
Webster Room 16	21.3	2.5	285	8
Webster Art Room	33.0	2.0	1313	16
Emerson Art Room	19.1	1.5	2200	8
LBPT Weight Lift	414	2.5	105	11

TABLE 5-10

HOSPITAL CHEMICAL DATA SUMMARY
EXISTING VENTILATION

Site	Ventilation Rate (CFM/Person)	Air Changes Per Hour	Hydrocarbon Content ($\mu g/m^3$)	Odor Level (ED_{50})
<u>Patient/Nurse Areas</u>				
LBG Patient Ward	50.3	3.4	49	17
UH Patient Room	80.8	4.2	795	6
SF Ward 602	1.4	0.1	712	18*
MS Ward 657	8.7	1.0	1756	7
HF Ward 522	1.5	0.2	1307	16*
VH Nurse Station	44.6	5.4	259	18
PH Nurse Station	66.9	5.3	872	12
UH Nurse Station	50.0	4.0	402	8
<u>Admissions/Waiting</u>				
UH Admissions Area	150	5.6	298	12
PH Admissions/Waiting	10.8	1.0	1612	12
VH Outpatient Admissions	49.4	3.0	309	9
LBG Admissions Office	109	3.4	43	10
MS Admissions/Emergency	37.8	4.2	121	7
HF Outpatient/Waiting	31.0	6.3	673	47*
<u>Labs/Misc.</u>				
LBG Clinical Lab	24.3	0.9	398	13
SF Histopathology	98.8	7.5	2079	16*
MS Histology	248	24.6	3493	53*
HF Cafeteria	17.4	5.9	2167	7*

*Some individual odorants above threshold on GC/odorogram.

areas at an average ventilation rate of 38.0 cfm/person; and 1990 $\mu g/m^3$ for clinical laboratories in spite of high ventilation rates of 124 cfm/ person. These results substantiate the low contribution of "occupancy odor" or population density to odors found in public buildings.

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